AD-A074 947 MARK RESOURCES INC MARINA DEL REY CA F/G 17/9

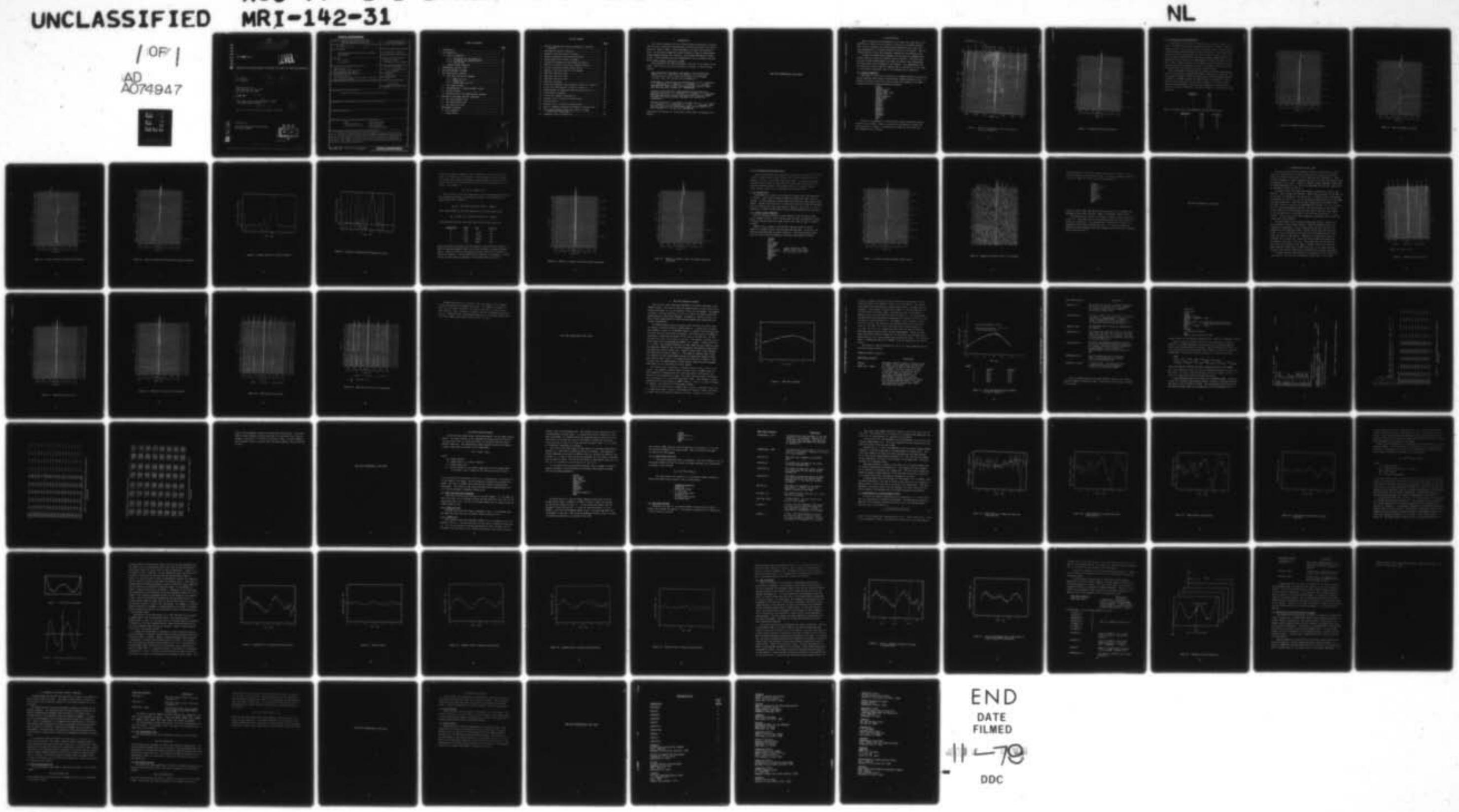
TMR PROCESSING PROCEDURES FOR GSRS SPIN AND ATTITUDE MEASUREMEN--ETC(U)

AUG 79 B D BAKER, W B KENDALL DAAD07-77-C-0094

UNCLASSIFIED MRI-142-31 NL

1 OF 1

AD
A074947

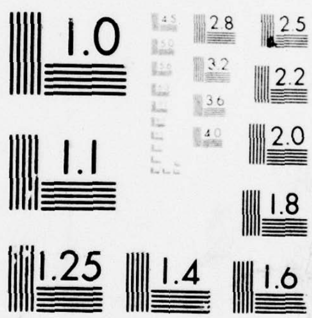


END

DATE FILMED

11-79

DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD A074947

MARK RESOURCES INCORPORATED

(2)

MRI REPORT-142-31

LEVEL II

TMR PROCESSING PROCEDURES FOR GSRS SPIN AND ATTITUDE MEASUREMENTS.

B. D. Baker
W. B. Kendall

Final rept. Aug 78 - Aug 79,

MARK Resources, Inc.
4676 Admiralty Way, Suite 303
Marina del Rey, CA 90291

AUGUST 1979

75

Final Report Under Contract DAAD07-77-C-0094
Mod P00003 and Mod P00006

1766580 4DE93

03

Approved for Public Release; Distribution Unlimited

Prepared for:

U.S. Army White Sands Missile Range
New Mexico 88002

391766

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: MRI Report 142-31	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): TMR PROCESSING FOR GSRS SPIN AND ATTITUDE MEASUREMENTS	5. TYPE OF REPORT & PERIOD COVERED: Final (Aug 78 - Aug 79)
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): B. D. Baker, W. B. Kendall	8. CONTRACT OR GRANT NUMBER(s): DAAD07-77-C-0094 Mod P00003 and Mod P00006
9. PERFORMING ORGANIZATION NAME AND ADDRESS: MARK Resources, Inc, 4676 Admiralty Way, Suite 303, Marina del Rey, CA 90291	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: DA Proj. No. 1T665804DE93-03 Task IT008F-G
11. CONTROLLING OFFICE NAME AND ADDRESS: Commanding Officer, U.S. Army White Sands Missile Range, STEWS-ID-T, White Sands, NM 88002	12. REPORT DATE: August 1979
	13. NUMBER OF PAGES: 77
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

GSRS
Motion Resolution
Instrumentation Radar
Precession Motion
Nutation Motion
Spin Frequency
Attitude Measurement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The use of Target Motion Resolution (TMR) processing of data from the MPS-36 and FPS-16 instrumentation radars at WSMR to produce measurements of the spin and coning motion of the GSRS surface-to-surface missile is described in detail. Actual flight-test data are processed to illustrate the techniques described. New computer software produced for and installed at WSMR to do the described processing is documented.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

347766

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

This report documents the use of TMR processing techniques to produce GSRS spin and coning motion measurements from data collected by the instrumentation radars at WSMR. These measurements are made from single-site data. Two software packages have been developed to make the measurements. Program WSGSRS measures spin frequency, and program TCM measures coning motion. These programs have been implemented on both the Univac 1108 and PDP-11 Radar Graphics Laboratory at WSMR.

Some familiarity with TMR processing on the part of the reader is assumed. This familiarity could be gained by a perusal of the following reports.

Radar Measurement Performance Improvement by Motion Resolution Methods (U), A. W. Rihaczek, W. B. Kendall, G. W. Lank, MARK Resources Report 110-11, Final Report under Contract DAAD07-75-C-0046, June 1975, AD-C002 333, CONFIDENTIAL.

Development of Improved Data Processing Methods (U), A. W. Rihaczek, P. A. Gartenberg, W. B. Kendall, J. J. Heimbold, I. P. Bottlik, MARK Resrouces Report 123-14, Final Report under Contract DAAD07-76-C-0019, May 1976, AD-C006 470, CONFIDENTIAL.

Feasibility Investigation of Motion-Resolution Processing for Artillery Shells (U), A. W. Rihaczek, W. B. Kendall, J. L. Dessinger, MARK Resources Report 123-23, Final Report under Contract DAAD07-76-C-0019, Modification P00001, December 1976, AD-C009 233, CONFIDENTIAL.

Improved Processing for Instrumentation-Radar Data (U), W. B. Kendall, A. W. Rihaczek, P. A. Gartenberg, G. W. Lank, J. L. Dessinger, MARK Resources Report 137-36, Final Report under Contract DAAD07-77-C-0028, December 1977, AD-C013 495, CONFIDENTIAL.

Familiarity with Section 3.2 of the last listed report is especially important.

THIS PAGE INTENTIONALLY LEFT BLANK

2. DATA REDUCTION

Before target motion measurements can be made, the radar data on the WSMR FPS-16 or MPS-36 site tape must be reduced via the WSPRC software. Both the spin frequency and coning motion programs use data which have been compensated for the gross trajectory motion of the missile. The processing required by the spin-frequency program will be described first.

In order to measure spin frequency, the data must be compensated to clearly show spin lines on a TMR plot such as Figure 1. The spin lines will give reliable measurements only when the central peak representing the base return is well aligned at zero Doppler. The compensation (for the trajectory) which aligns the central peak is carried out in two steps: (1) the initial correction; and (2) the lowpass-filter correction.

2.1 INITIAL CORRECTION

The result of the initial correction is compensated data for which the central spectral peak (from the missile base) remains between ± 20 Hz. To produce the initial correction, the site tape is processed by the WSPRC software with the following parameters specified:

```
$PARMS
LEVEL=1,1,1,1,1,
GENTAP=.TRUE.,
TBIAS=(launch time),
PRF=320.1729,
FREQ=(frequency),
AUTØR=.TRUE.,
XKNTSR=0.,
SUBDVR=4,
NAVGR=8,
SUBDVP=3,
NAVGP=8,
BRKMNP=0.,
DØPPLT=1.,
NFFT=256,
LENWDW=64,
LAG=16,
$END
```

Figure 2 is an example of a satisfactory initial correction produced by such a run of WSPRC. When the initial fit satisfactorily aligns the central peak as in Figure 2, processing continues with the second step, the lowpass-filter correction.

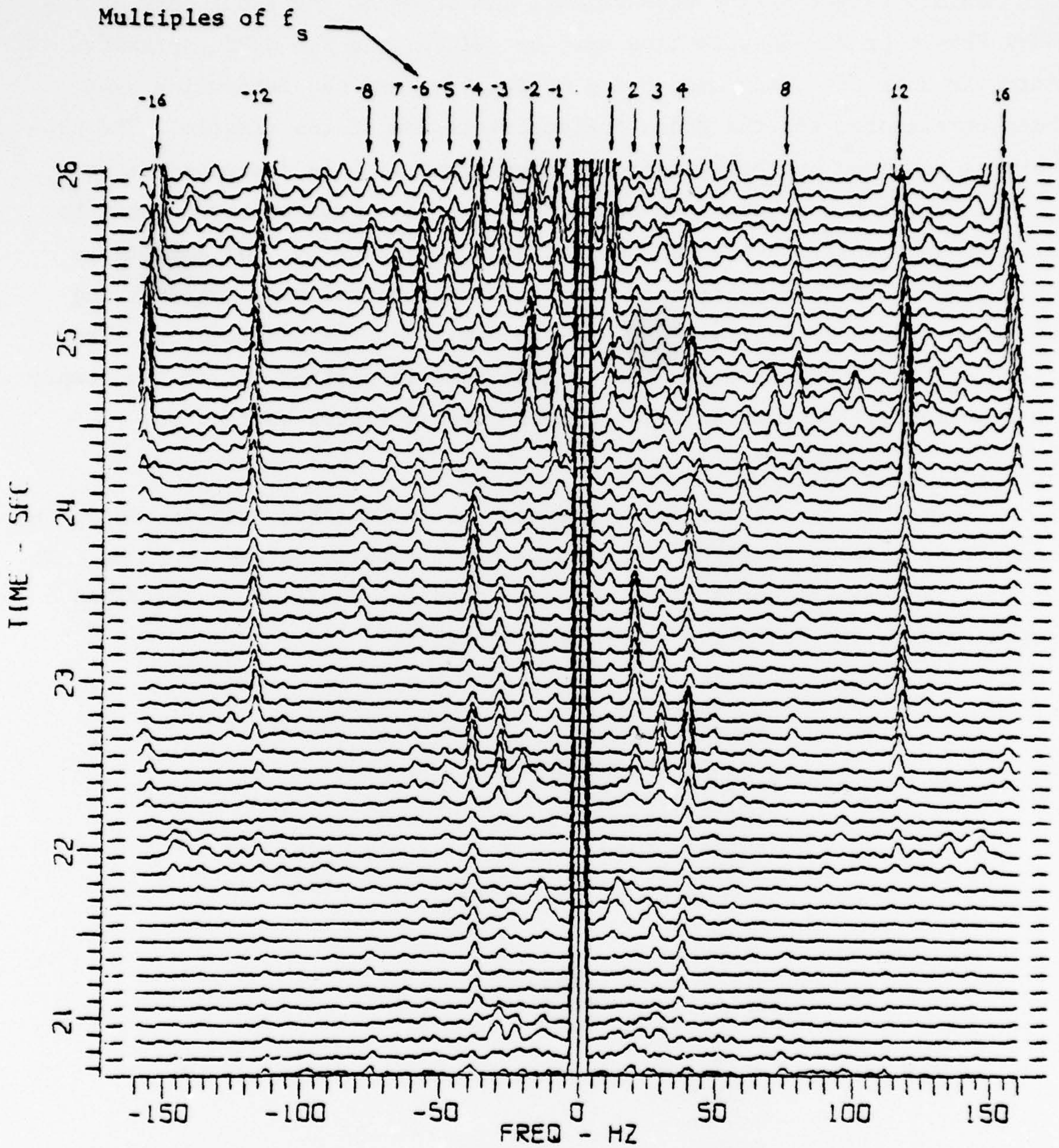


Figure 1. TMR Plot Showing Spin Lines at Multiples of the Spin Frequency f_s

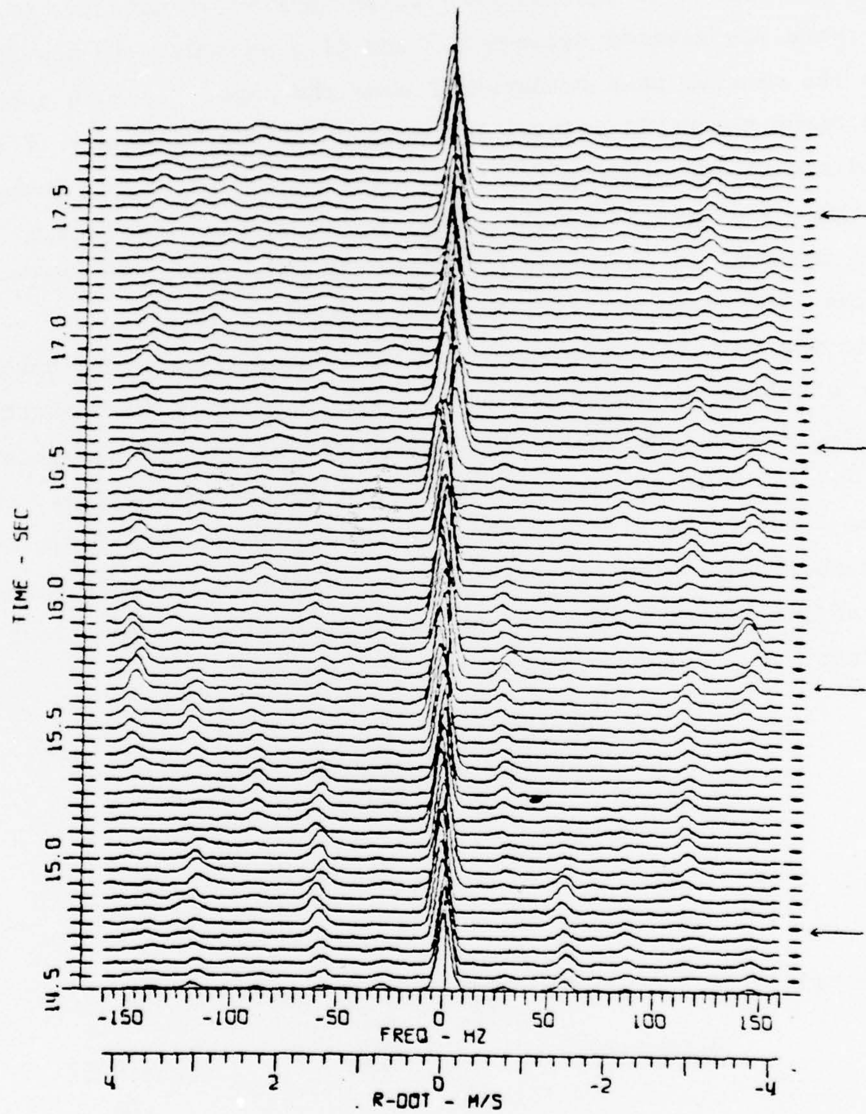


Figure 2. Satisfactory Initial Correction

2.1.1 Processing with Bad Range Data

Occasionally the initial run of WSPRC will not produce satisfactory results. The TMR plots may show sections of bad data or clutter. Figure 3 shows the result of an initial correction applied to data for which the recorded range was invalid between 9.5 and 11.5 seconds. In the bad section of data the central peak wanders all over the page. In such a case it is best to rerun the WSPRC initial correction, setting parameter EDIT=5, and using edit cards to specify the time interval for which the range data are bad. Figure 4 shows the result of the WSPRC initial correction for which bad-data interval is specified as 9.5 to 11.5 seconds. The main peak now oscillates about zero Doppler, but stays within ± 50 Hz.

When the initial correction does not center the central peak between ± 20 Hz, a spline may be generated by hand to improve the correction. The R-dot Peaks (or Doppler Peaks) plot generated by setting parameter DØPPLT=1. in LEVEL(5) of WSPRC is useful in constructing the hand spline. Figure 5 shows the R-dot Peaks plot for the data of Figure 4. The first step in creating the hand spline is to select the breakpoints at the peaks and valleys of the R-dot Peaks plot, as shown in Figure 6. The first few breakpoints are:

BREAKPOINT	TIME
1	4.82
2	5.61
3	6.50
4	6.92
5	7.35

Next, the values of $\dot{R}$ at the breakpoints are read from the plot:

BREAKPOINT	TIME	$\dot{R}$ (m/sec)
1	4.82	.05
2	5.61	-.02
3	6.50	.02
4	6.92	-.06
5	7.35	.09

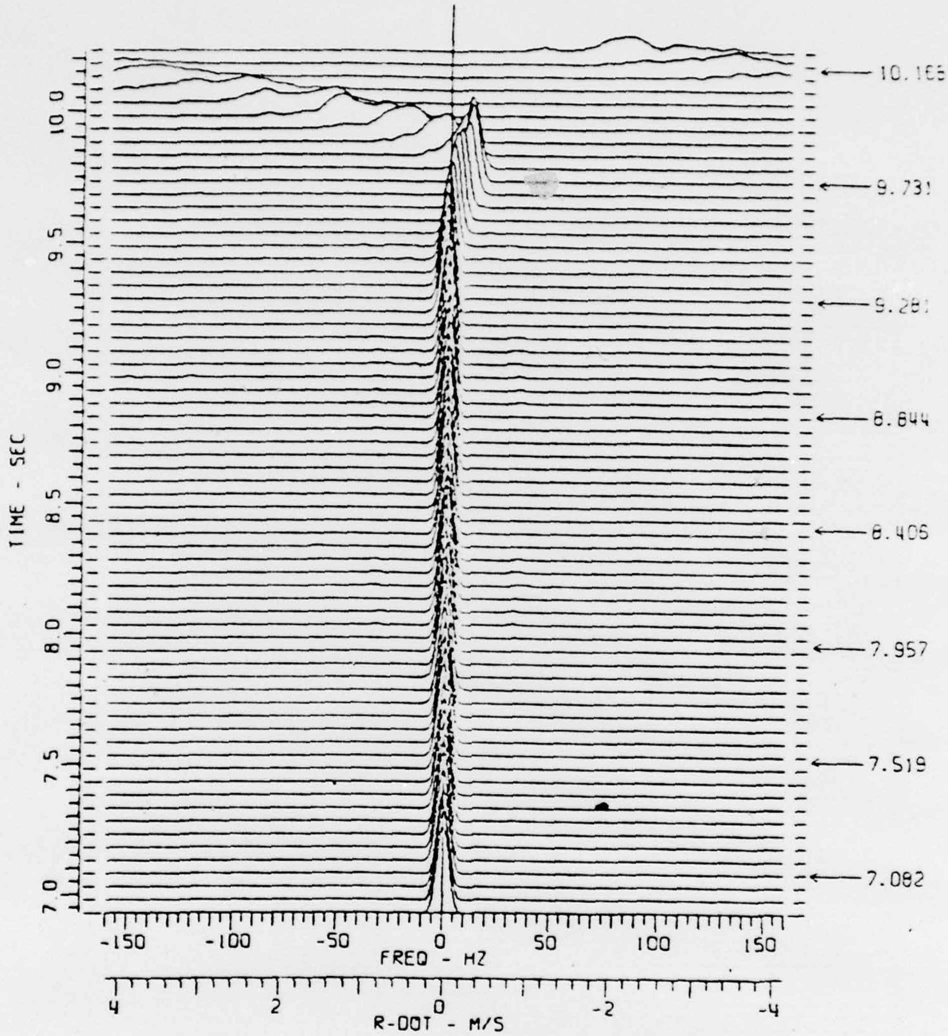


Figure 3a. Example of Bad Data after 10 Seconds

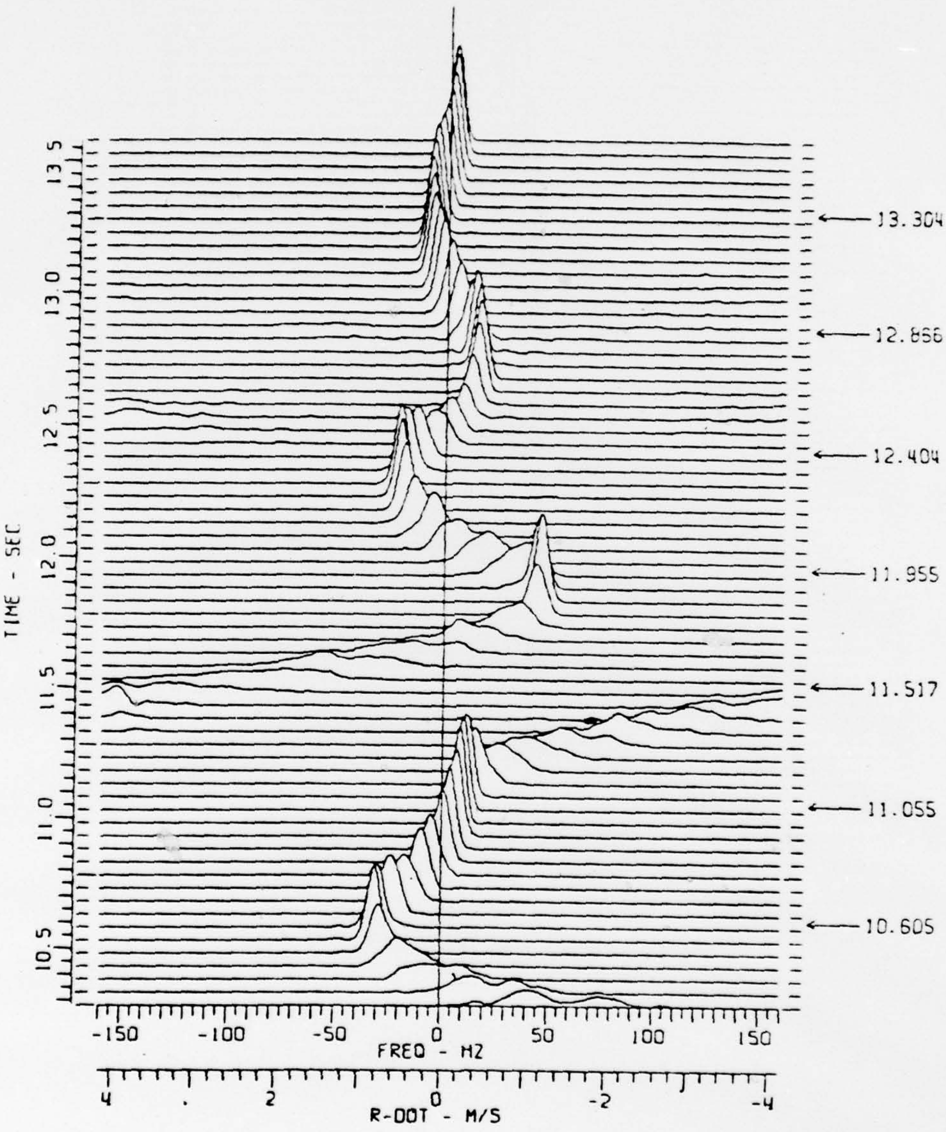


Figure 3b. Bad Data Example (Continued)

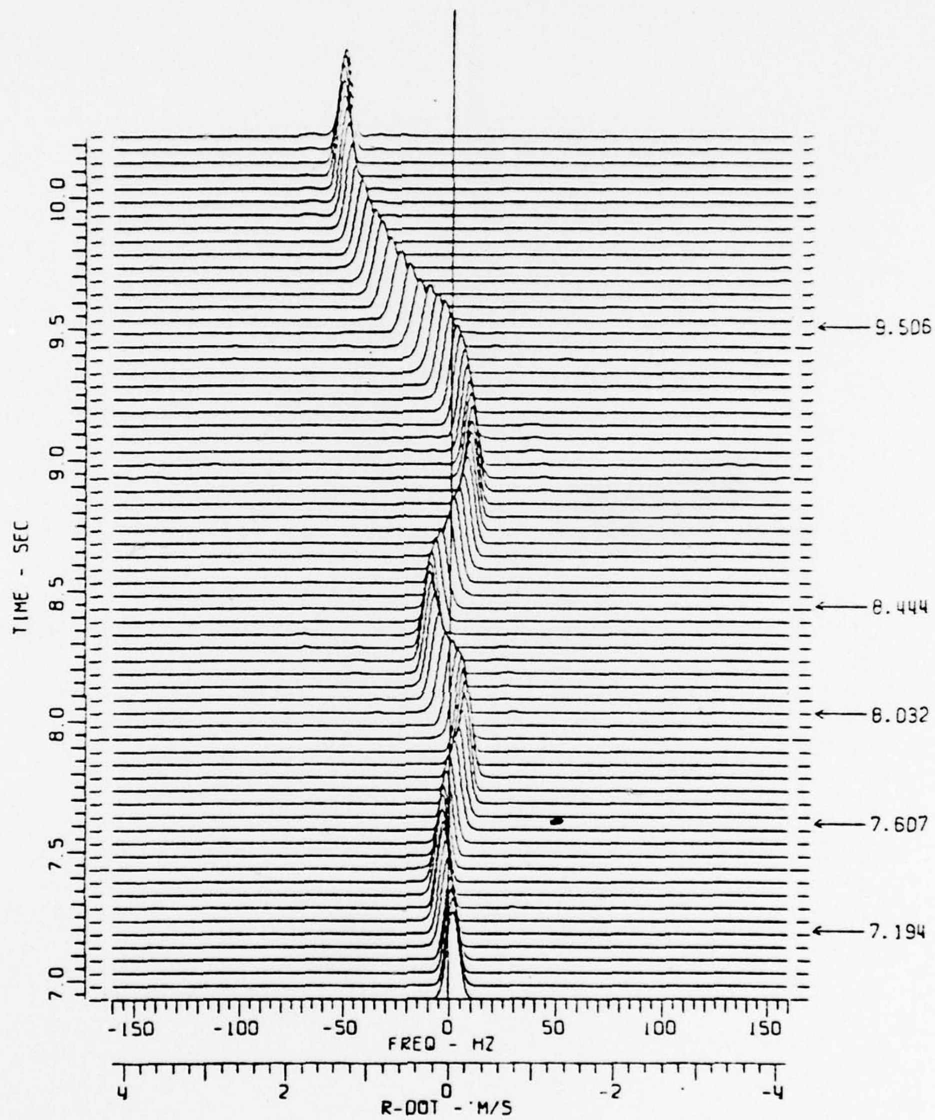


Figure 4a. Initial Correction with Bad Section Edited

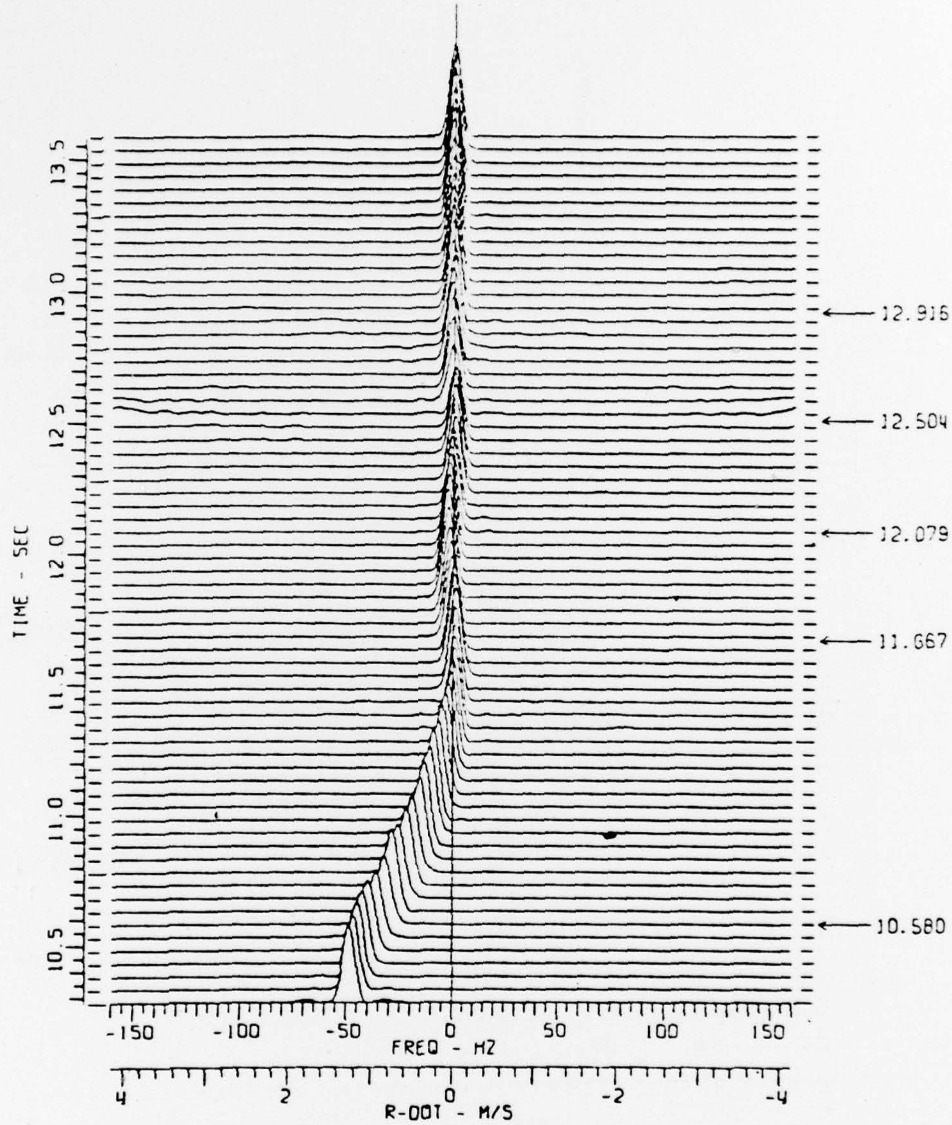


Figure 4b. Initial Correction with Bad Section Edited (Continued)

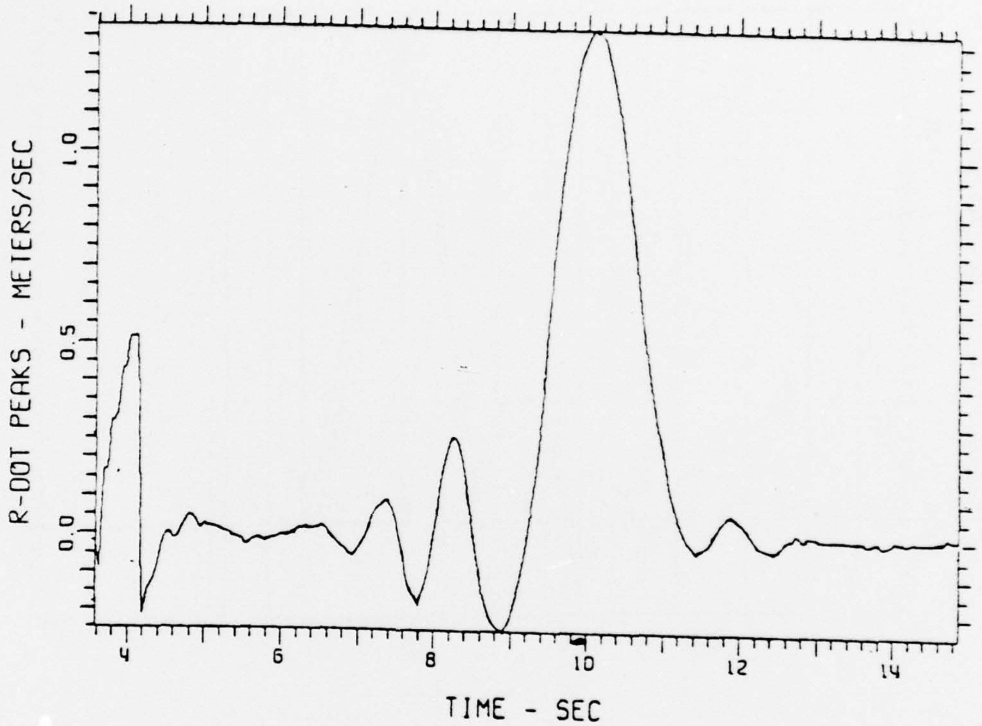


Figure 5. Doppler Peaks Plot of Data of Figure 4

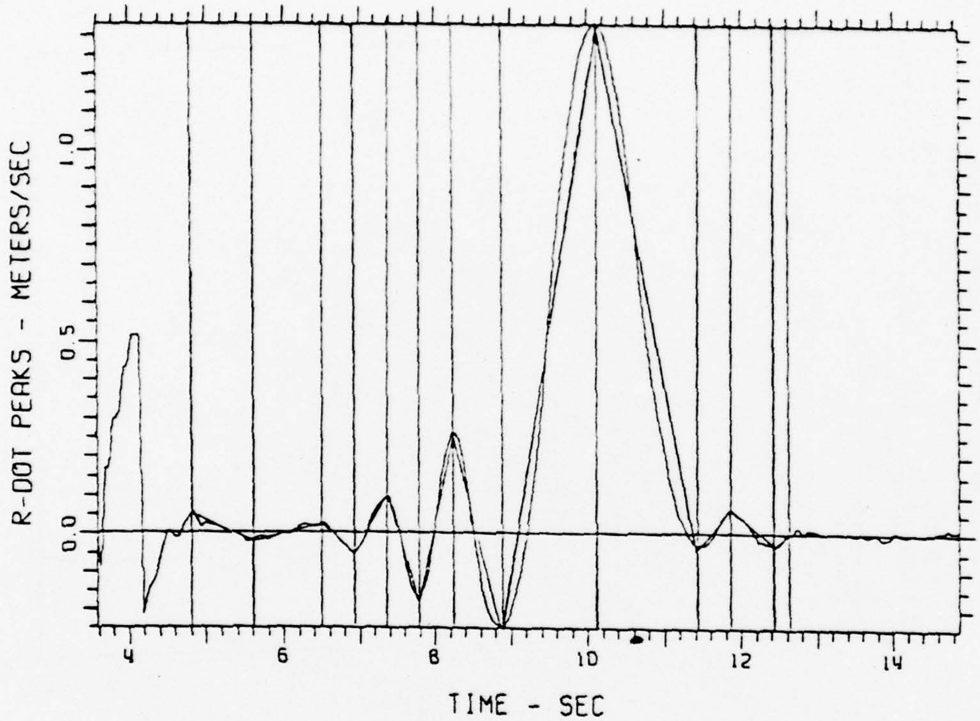


Figure 6. Picking the Breakpoints and Drawing the Spline

Finally, the range is computed at each breakpoint, and the spline is complete. The range value at the right of each breakpoint *interval* is given by a formula which uses the previously computed range value R_L at the left of the interval, and the time and $\dot{R}$ values at the left and right of the interval. The formula is

$$R_R = R_L + \frac{1}{2}(\dot{R}_L+\dot{R}_R)(T_R-T_L) \quad .$$

Zero is used for the first range value, and the succeeding range values are calculated according to the recursive formula. In this example the second range value is given by

$$R_R = 0. + \frac{1}{2}(.05+(-.02))(5.61-4.82) = .01185 \text{ m} \; .$$

This value becomes R_L for the computation of the next range value:

$$R_R = .01185 + \frac{1}{2}(-.02+.02)(6.50-5.61) = .01185 \text{ m} \; .$$

Continuing this process, the first five points of the spline are:

BREAKPOINT	TIME	R(m)	$\dot{R}$ (m/sec)
1	4.82	0.	.05
2	5.61	.01185	-.02
3	6.50	.01185	.02
4	6.92	.00345	-.06
5	7.35	.0099	.09

These spline data are entered into the computer, and then read in LEVEL(4) of WSPRC by setting parameters IØ4=5 (for cards) and IØ5=0 in namelist $PARMS. Figure 7 shows the result of applying the spline correction from Figure 6 to the data in Figure 4. One more hand spline correction is necessary to further correct the data before proceeding to the lowpass filter correction.

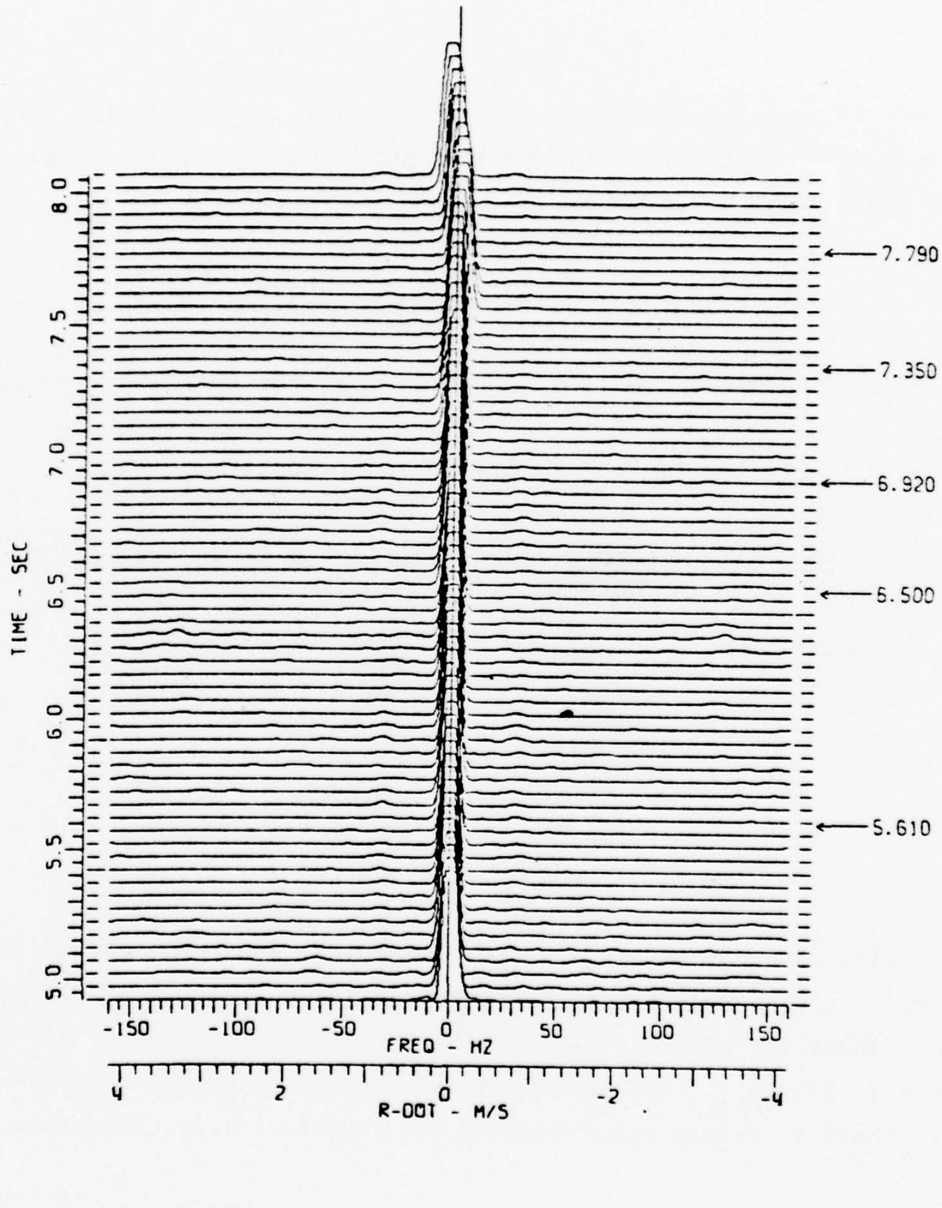


Figure 7a. TMR Plot of Figure 4 Data After Spline Correction

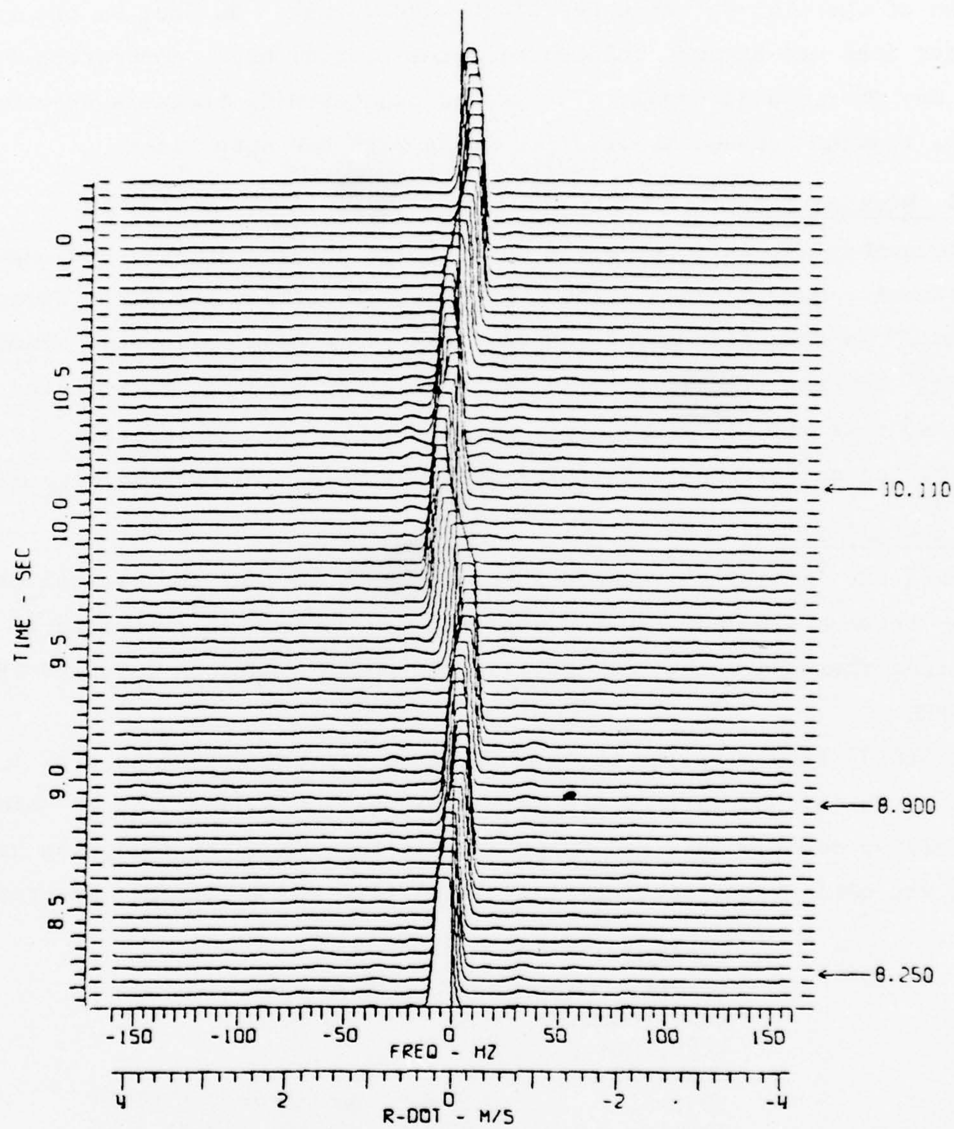


Figure 7b. TMR Plot of Figure 4 Data After Splin Correction (Continued)

2.1.2 Processing with Ground Clutter

Another problem which may appear during the initial correction is ground clutter. Figure 8 shows ground clutter, the strong line moving from the bottom of the plot to the upper right-hand corner. As long as the ground clutter does not become confused with the central peak, correction of the data may continue as usual. The ground clutter will become a nuisance later, though, because it will interfere with the spin lines.

2.1.3 Missing Data

Occasionally, an interval of data may be no good at all, and impossible to correct. Such a case is shown in Figure 9 between the times 24 and 26 seconds. In that figure the central peak from the missile base seems to disappear. Lowpass filtering fails to provide any clues as to what was happening here, so this section of the data should be ignored. Most often, it will be possible to correct the data fairly well by using splines wherever necessary.

2.2 LOWPASS FILTER CORRECTION

Once the initial correction is good enough so that the central peak stays between -20 and + 20 Hz, the data may be further corrected by lowpass filtering them and using the lowpass filter (LPF) data as input to LEVEL(3) of WSPRC.

LEVEL(3) fits a spline to the LPF data, and the spline is used in LEVEL(4) to further correct the initially-corrected data. To do this, the initially-corrected data are input on unit 11. Then the following parameters are used in the Acceleration, Filtering, and Decimation Program:

```
$SPARMS
IØ3=12,
ACC=.FALSE.,
LPF=.TRUE.,
NBAND=32,
IDEC=5,              (Other parameters, STRTME,
TMRPLT=.TRUE.,       ENDTME, SCLFCT, PKHT, TRNC,
DØPPLT=1.,           etc., are used as in WSPRC.)
NFFT=64,
LENWDW=16,
LAG=4,
$END
```

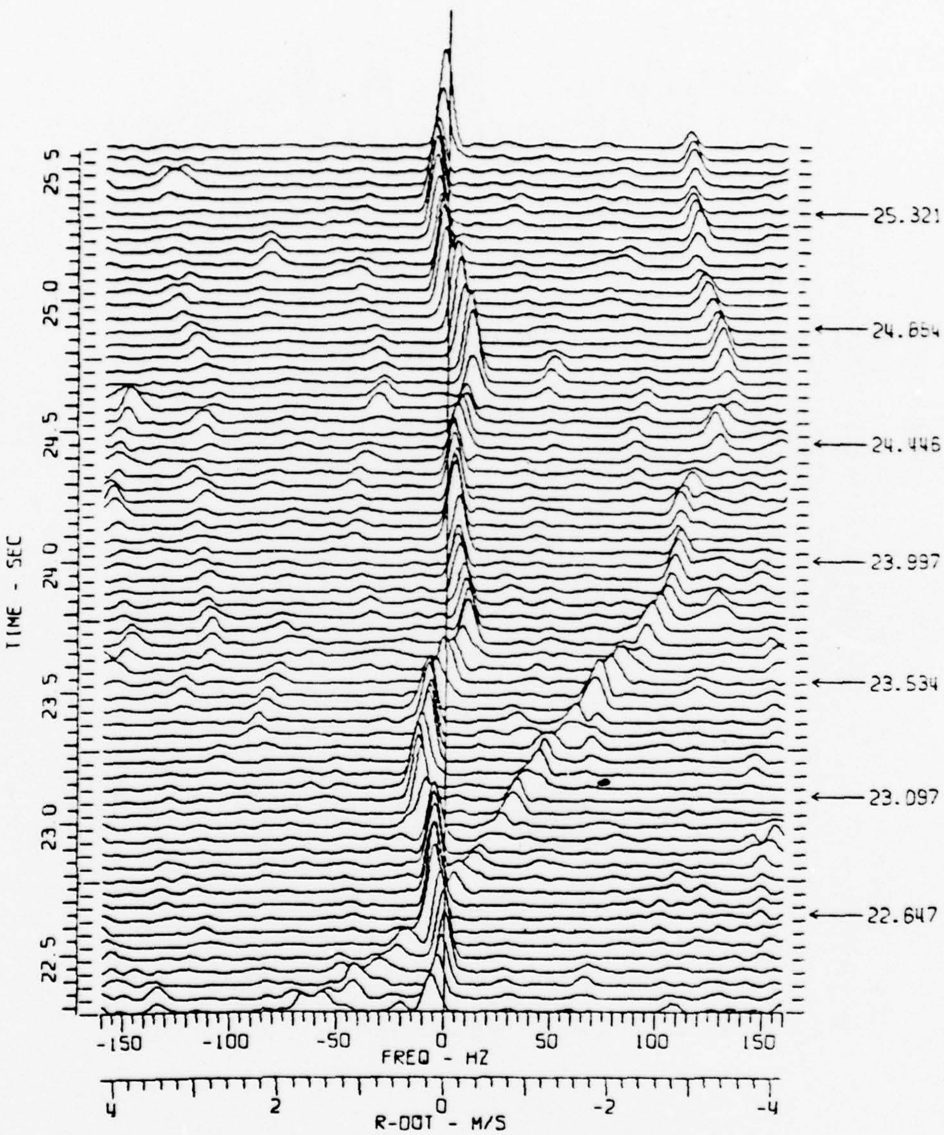


Figure 8. Initial Correction Showing Ground Clutter

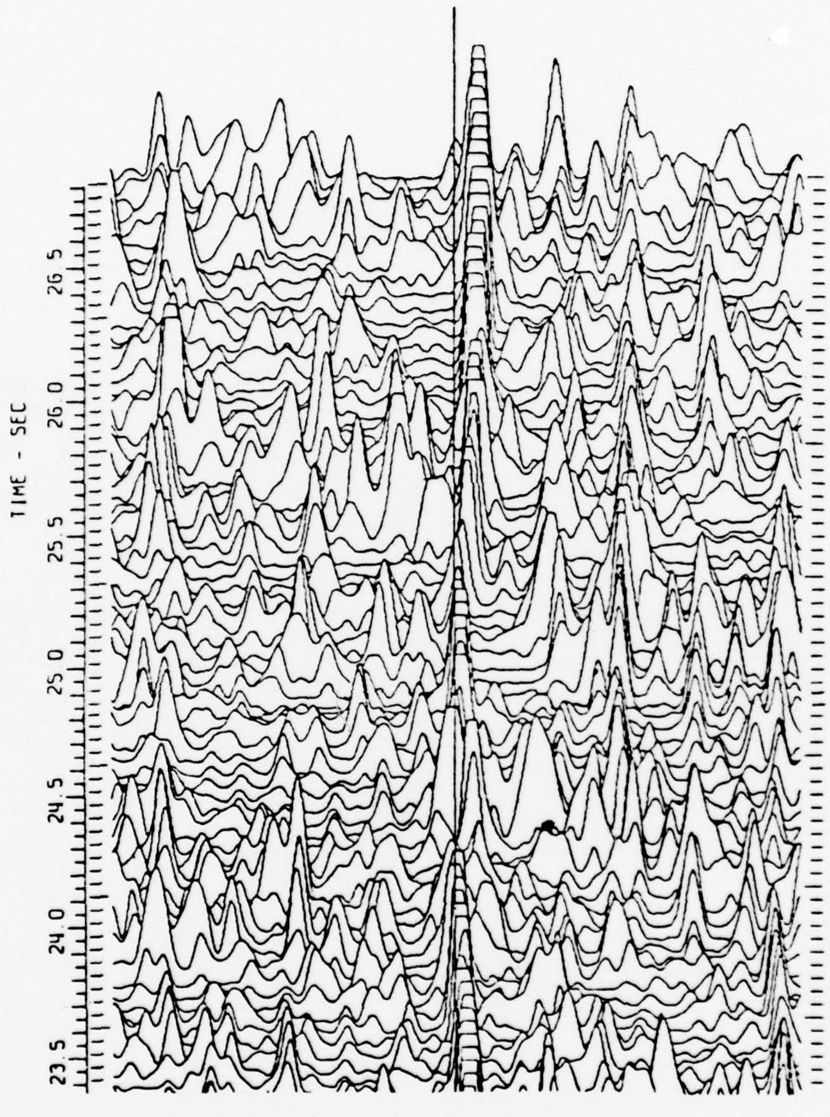


Figure 9. Example of Bad Data from 24 to 26 Seconds

This procedure will output the lowpass-filtered data on unit 12. Next, with the initially-corrected data on unit 11, and the lowpass-filtered data on unit 12, WSPRC is run with the following parameters.

```
$PARMS
LEVEL=0,0,1,1,1,
XKNTSP=-.2,
NAVGP=3,
IØ4=0,
DØPPLT=1.,
NFFT=512,
LENWDW=160,
LAG=32,
$END
```

Values of SCLFCT, PKHT, and TRNC should be chosen to give a readable plot showing the spin lines (SCLFCT=0., PKHT=4., and TRNC=1. usually work).

This procedure will place the outputted, lowpass-filter-corrected data on unit 13. From this stage in the processing,clear spin lines should be visible on the TMR plot. An unsatisfactory correction will result in a misaligned central peak and weak spin lines. If further correction is needed, the above procedure should be repeated using the recently corrected data as input on unit 11.

THIS PAGE INTENTIONALLY LEFT BLANK

3. INTERPRETING THE SPIN LINES

Now that the spin lines are clearly visible on the TMR plot, the next step is to identify them. The GSRS target has four fins, so strong spin lines will be seen at multiples of four times the spin frequency f_s. Since the spin frequency is usually between 8 and 10 Hz, the spin lines usually occur at spacings of 32 to 40 Hz. Figures 10 through 12 show examples of spin lines at various multiples of 4 f_s. In all of these TMR plots the spin lines occur at intervals of about 30 to 40 Hz.

In Figure 10 the -20 f_s spin line appears on the positive side of the TMR plot. This is known as "foldover." When a spin line goes off the TMR plot at one side, it continues on the other side. In Figure 12 spin lines appear at multiples of up to 32 f_s. All of the lines at multiples of 20 f_s and higher have been folded over. The left and right boundaries of the TMR plot are at $\pm$ PRF/2, which in this case is approximately $\pm$ 160 Hz. So, if f_s = 10 Hz, the 20 f_s spin line appears at 200 Hz. But the plot goes to only 160 Hz, so this line will be 40 Hz beyond the right edge of the plot, which means it will be seen 40 Hz to the right of the left side of the plot, i.e., at -120 Hz. It is as if the plot were wrapped on a cylinder, with the left and right sides joined together.

The spin lines are not always straight and vertical, because the spin frequency is not always constant. The spin frequency may be increasing or decreasing. If it is increasing, the spin lines will be spreading out and getting farther from the central peak and from each other. If f_s is decreasing, the lines will be getting closer to each other and closer to the center. This may look confusing if there is foldover, as in Figure 12a. There the spin frequency increases from the bottom to the top of the plot. This means that all the positive spin lines are slanting to the right. However, half of the positive spin lines are folded over, so when they slant to the right they get closer to the center, though their frequencies are actually increasing.

In Figure 12b the spin frequency is decreasing, so all the positive lines slant to the left, and the negative lines slant to the right.

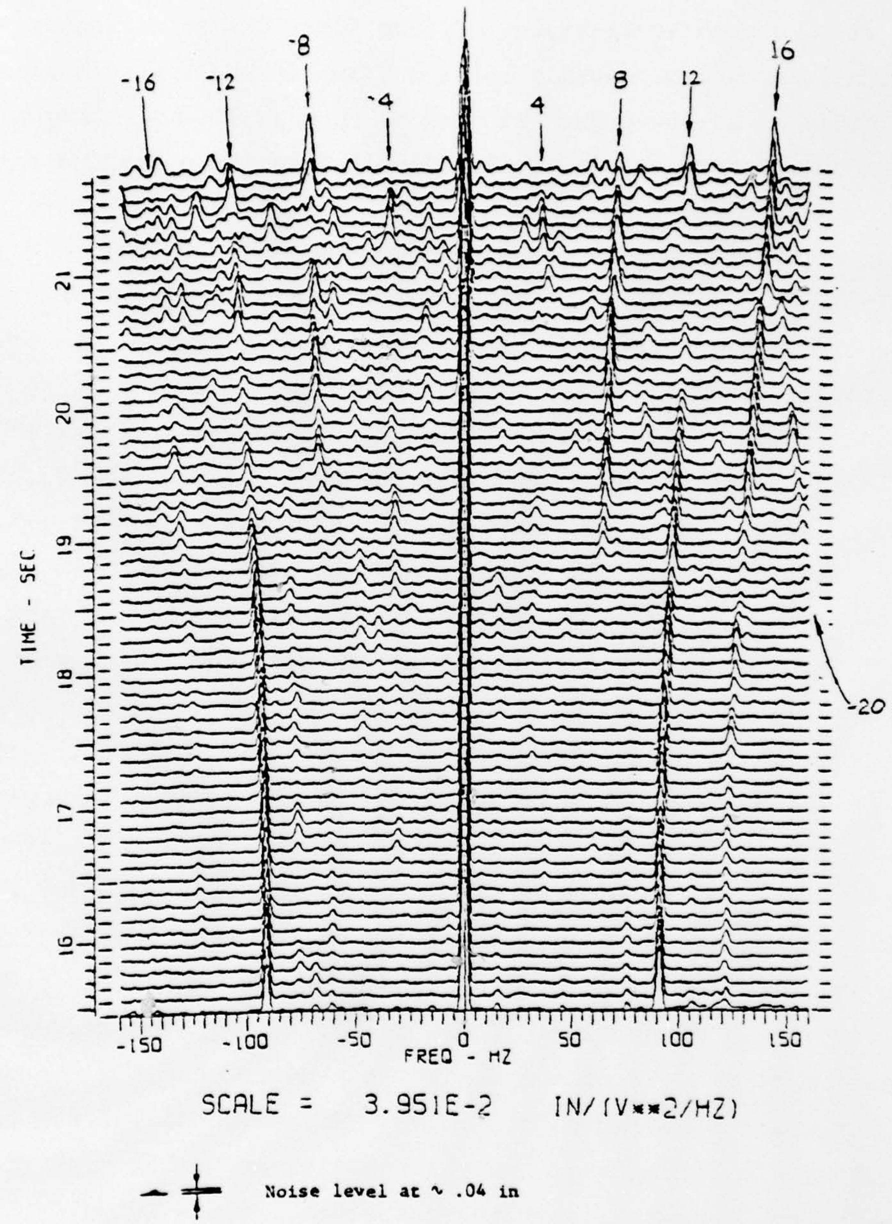


Figure 10. GSRS Data from Site R-394

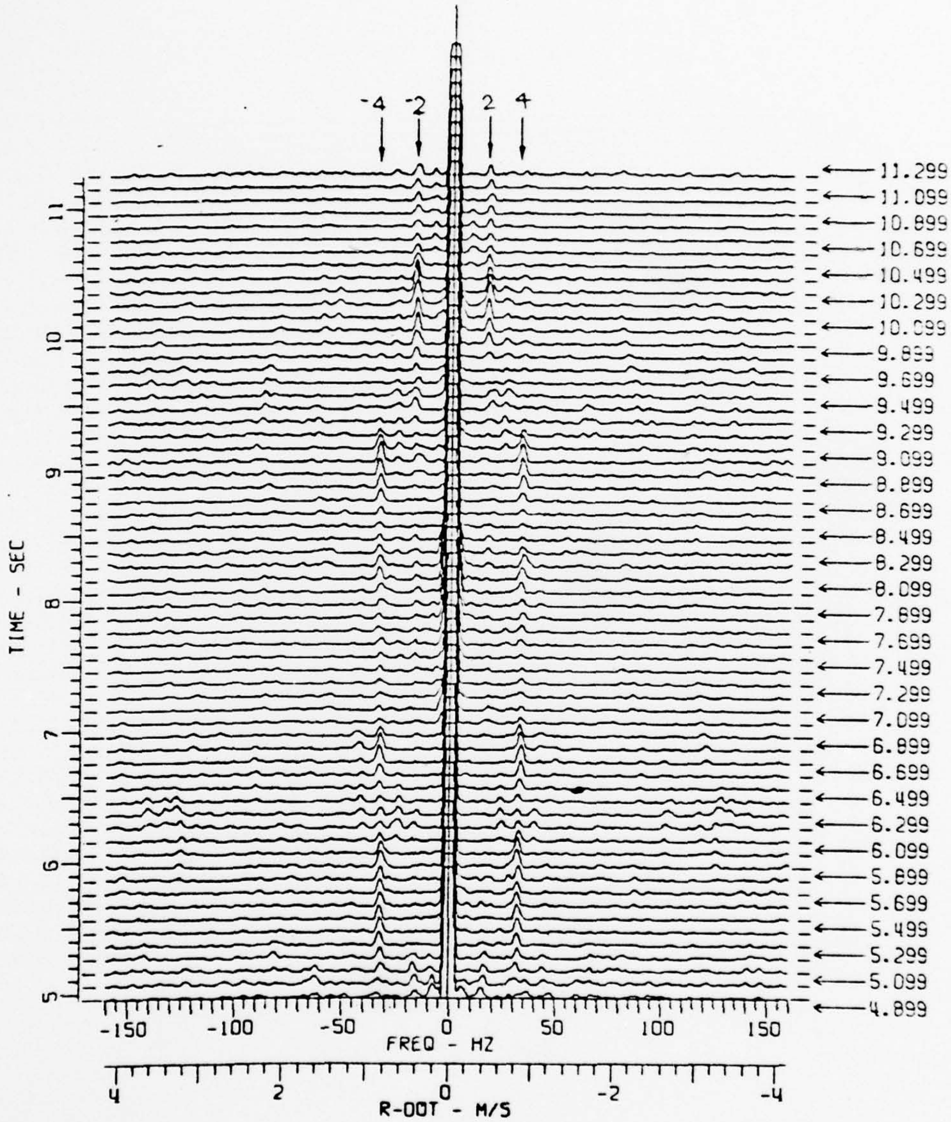


Figure 11a. GSRS Data from Site R-113

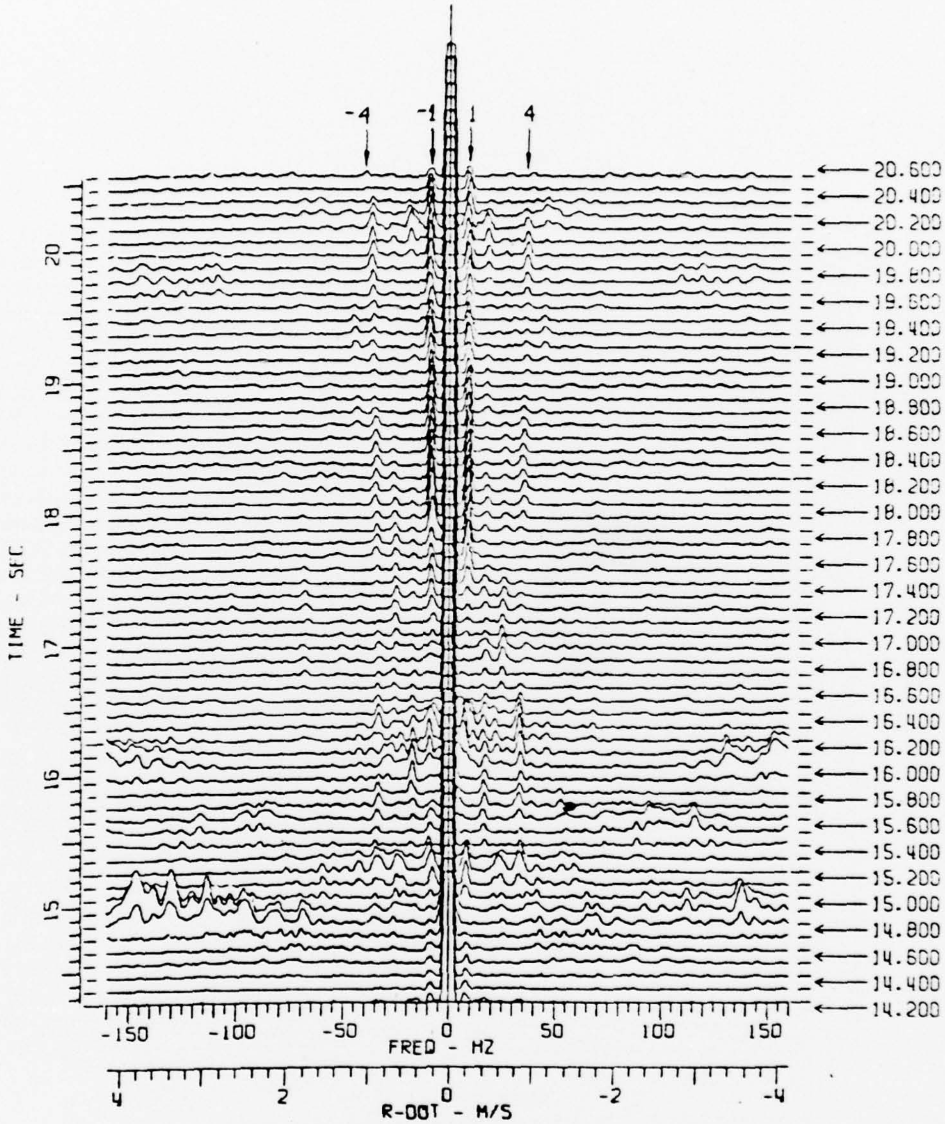


Figure 11b. GSRS Data from Site R-113 (Continued)

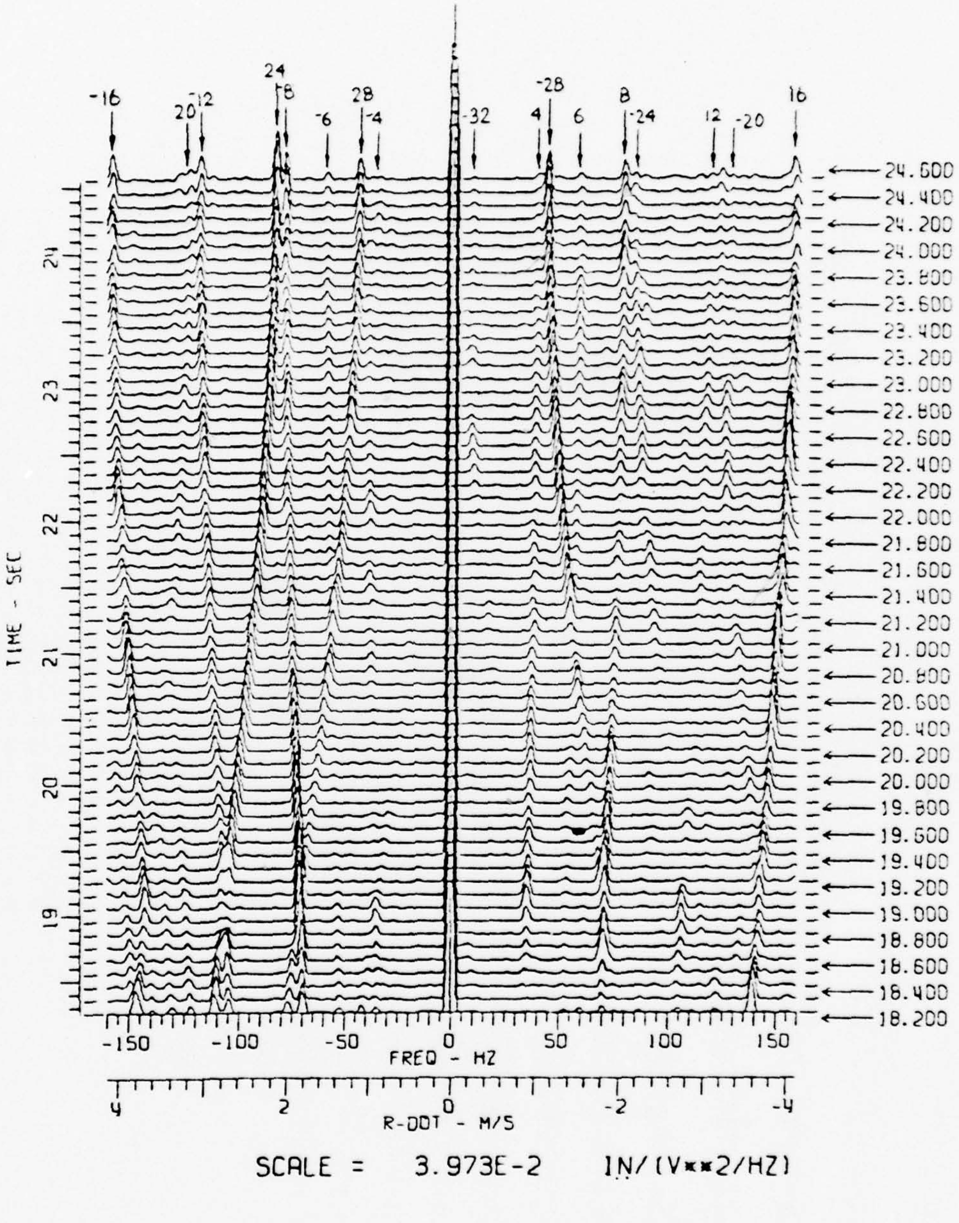


Figure 12a. GSRS Data from Site R-395

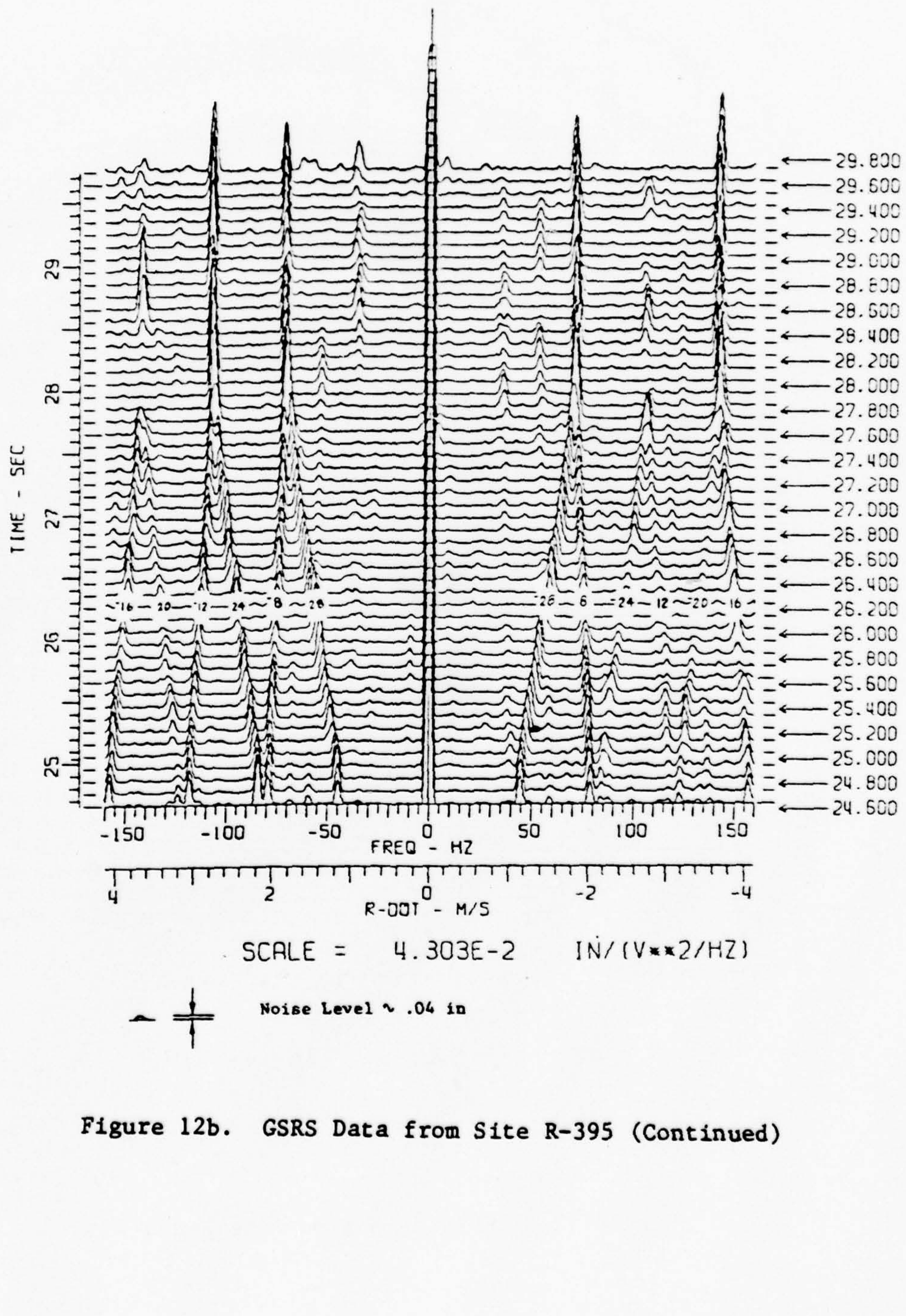


Figure 12b. GSRS Data from Site R-395 (Continued)

Another characteristic to notice is that the change in spin frequency is more pronounced in the higher-order lines. For example, in Figure 12a the 28 f_s line slants strongly to the right, while the 4 f_s line looks almost vertical. This, of course, is because the lines are spaced at multiples of 4 f_s. Therefore, when the spacing changes due to a frequency change, the 28 f_s line changes seven times as much as the 4 f_s line.

THIS PAGE INTENTIONALLY LEFT BLANK

4. THE SPIN FREQUENCY SOFTWARE

Once the spin lines have been identified, they may be analyzed by the WSGSRS program. Four positive and four negative pairs of spin lines at consecutive multiples of 4 f_s are selected for use in the program. For example, in Figure 1 the spin lines at $\pm$ 4, $\pm$ 8, $\pm$ 12, and $\pm$ 16 times the spin frequency should be used by the program. In Figure 12, the $\pm$ 16, $\pm$ 20, $\pm$ 24, and $\pm$ 28 spin lines should be chosen because higher-order lines give more accurate measurements.

The WSGSRS program tracks the peaks of the selected spin lines using the Fourier transform software of WSPRC LEVEL(5). A noise level threshold value THRESH is input in the $TRCKER namelist to specify the power level below which the spin lines should be ignored. The proper value for THRESH is determined by measuring the height of the noise on the TMR plot, and then dividing this value by the scale of the plot. For example, in Figure 10 the noise level would be approximately THRESH = 0.04 inches ÷ 0.03951 in/(v^2/Hz) $\simeq$ 1.0 v^2/Hz. The program determines for what times the spin lines are above the specified threshold, and the spin frequencies represented by these spin-line peaks are plotted versus time. Figure 13 shows such a spin-frequency plot made from the data of Figure 12. The jumps in frequency near 19 and 27.4 seconds are false measurements caused by interference between folded spin lines at those times. It is seen from the TMR plot in Figure 12 that the spin lines are superimposed in these regions, hence the spin frequency measurement will be inaccurate for these regions.

The software has two methods of tracking the spin lines; automatic and guided. The automatic tracker tracks the spin lines at $\pm$ LØWFS times the spin frequency by searching for each successive peak on the basis of the position of the preceding two peaks. The other spin-line peaks are searched for at intervals of 4 f_s from the lower-order lines. This automatic tracker requires distinct spin lines at $\pm$ LØWFS times f_s. The $\pm$ 4 f_s lines in Figure 1, for example, are suitable for the automatic tracker.

Usually the spin lines at $\pm$ LØWFS times f_s are not completely clear, due to a high noise level; or due to interference by clutter or other spin lines. In these cases the automatic tracker is not used. Instead, the spin-line

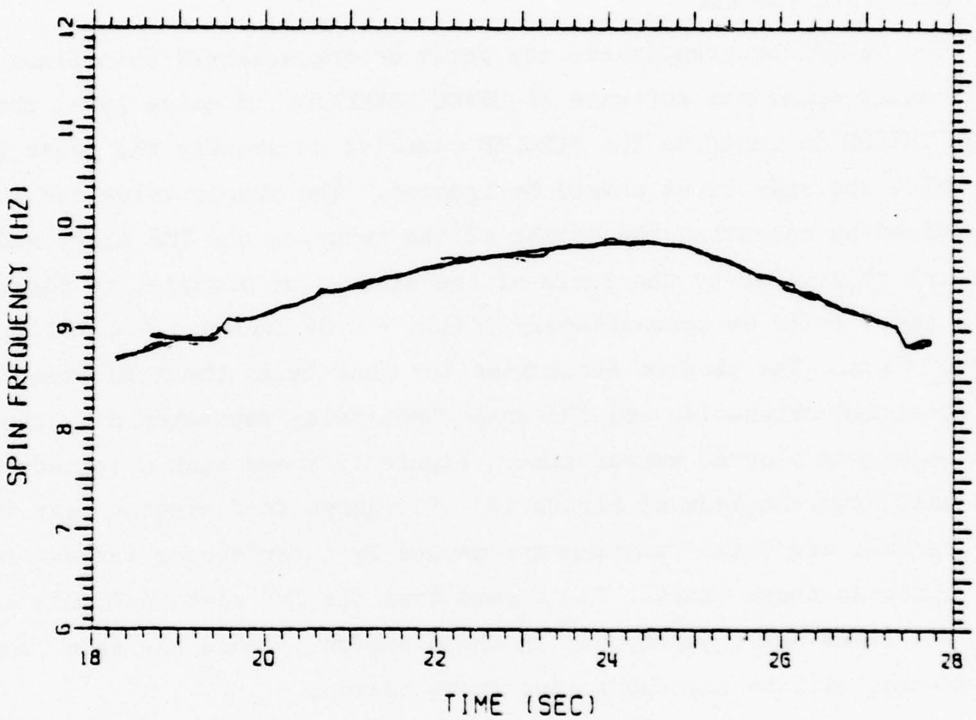


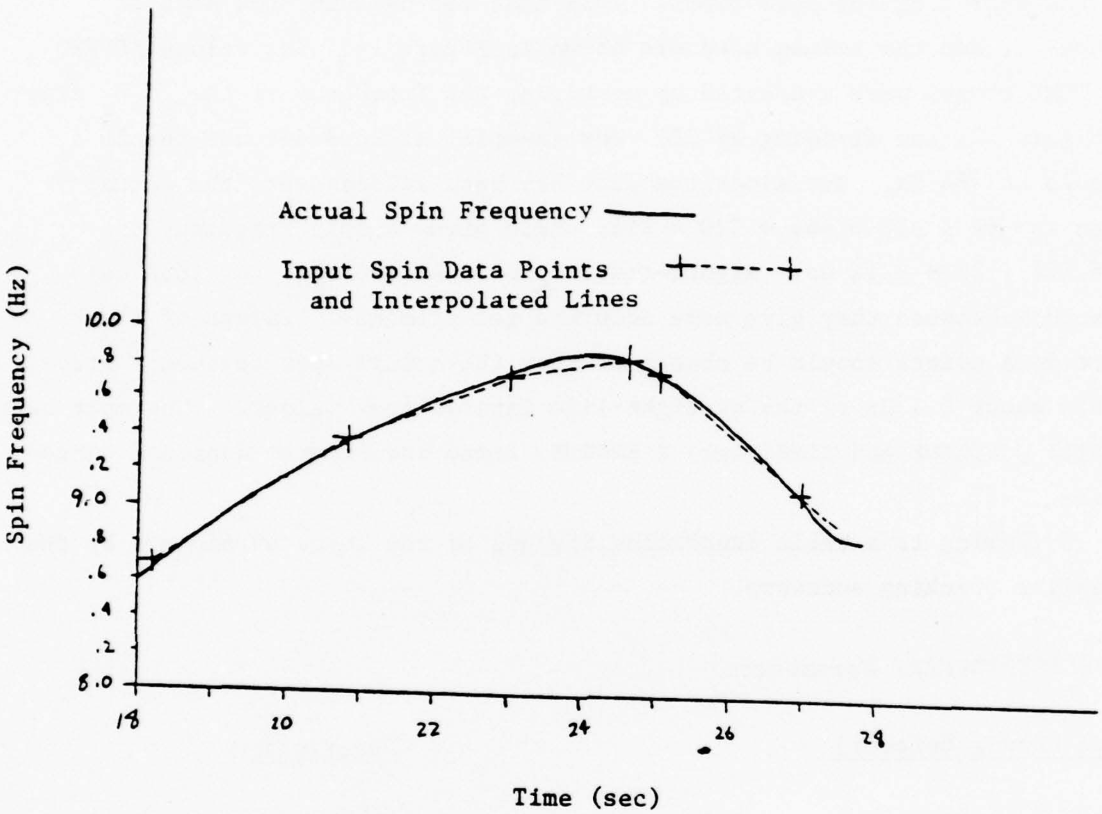
Figure 13. GSRS Spin Frequency

tracker is guided by input data points specified by the namelist arrays SPNFRQ and TIME, where SPNFRQ(I) equals f_s at time TIME(I). The program uses straight-line interpolation between these points to estimate the spin frequency. The estimate is multiplied by LØWFS to find the starting point for the search of the spin lines. This mode was used for the data of Figure 12, and the values used are shown in Figure 14. The values SPNFRQ and TIME chosen were evaluated by measuring the frequency of the 28 f_s line in Figure 12, and dividing by 28. For example, at 26.9 seconds the 28 f_s line is at -64 Hz. But since the line has been folded over, the actual value is $-64 + PRF = -64 + 320 = 256$, which gives a spin frequency of $f_s = 256 \div 28 = 9.14$ Hz. Higher-order spin lines are used for such calculations because they give more accurate measurements. Enough of these input data points should be chosen so that the actual spin frequency stays within about 0.1 Hz of the straight-line interpolated values. One must have TIME(1) $\leq$ STRTME and TIME(last) $\leq$ ENDTME, since the program does not extrapolate.

Following is a table describing the use of the input parameters by the spin-line tracking software.

NAMELIST/TRCKER/ Parameters:

Name (Type, Default)	Description
$TRCKER	
AUTØT (LOG.,.TRUE.)	Determines whether automatic tracking is used. If .TRUE., the program tracks the spin lines by following the peaks of the lowest spin line (LØWFS). But this automatic tracker is unpredictable if the data are bad or if the spin lines are ambiguous. For such cases use AUTØT=.FALSE. When AUTØT=.FALSE., breakpoints specifying time and spin frequency are read in through the variables TIME and SPNFRQ. Straight-line interpolation between these points then guides the tracker.



Input:

I	TIME(I)	SPNFRQ(I)
1	18.2	8.68
2	20.8	9.39
3	23.0	9.75
4	24.6	9.85
5	25.05	9.79
6	26.9	9.14

Figure 14. Actual and Estimated Spin Frequency for Data of Figure 12

Name (Type, Default)	Description
LØWFS(INT.,4)	The multiple of the spin frequency represented by the lowest frequency line to be tracked. The tracker follows lines at ±(LØWFS+0, +4,+8,+12); 8 lines in all.
STRTHZ(REAL,8.)	The spin frequency (Hz) at the start of the tracking period. The auto-tracker starts looking for spin lines at ±STRTHZ*LØWFS. If AUTØT= .FALSE., STRTHZ need not be specified, as it is calculated from the input breakpoints.
IØ98(INT.,98)	The temporary unit to which the tracking data are written.
THRES(REAL,100.)	The noise level threshold (v^2/Hz) of the Doppler peaks power spectrum. When the spin-line power falls below this level it is ignored. The value for this parameter must be carefully chosen from the previous TMR plots.
TIME(REAL,20*-1.)	The array containing the breakpoint times to be used in calculating the spin frequency for the tracker. The spin frequency is SPNFRQ(I) at time TIME(I). Only the values of TIME preceding the first negative value are used.
SPNFRQ(REAL,20*8.)	The spin frequencies (Hz) at the times TIME. These values must be estimated from the previous TMR plots.
PLTLNS(LOG.,.FALSE.)	If PLTLNS=.TRUE., a frequency plot and a power-level plot will be generated for each of the eight spin lines.

Since the WSGSRS software uses WSPRC LEVEL(5) software, the LEVEL(5) namelist $PARMS is required as input. The deck set up for input to WSGSRS is as follows:

```
.
.
.
.
@ EØF Card
Header Card
$PARMS
LEVEL=0,0,0,0,1,
STRTME=...,ENDTME=...,IØ3=...,
IØ6=0,
TMRPLT= .FALSE., (We assume that suitable TMR plots
DØPPLT=1.,           have been previously generated.)
NFFT=..., LENWDW=..., LAG=...,
$END
$TRCKER
    Tracker parameters
$END
@EØF or other master-space card
```

(Usual values for the LEVEL(5) parameters are: NFFT=512, LENWDW=160, LAG=32.)

Figure 15 shows the printer output from the analysis of the data of Figure 12. The WSPRC parameters are printed, then the WSGSRS parameters, then the data from the spectral tracking. These tracking data are written to the unit specified by the variable IØ98, and may be plotted by specifying PLTLNS=.TRUE. The data are written in groups of 17 values in the order

time,
$freq_{-L}$, amp_{-L}, $freq_{L}$, amp_{L}, $freq_{-(L+4)}$, $amp_{-(L+4)}$, ... ,
$freq_{(L+8)}$, $amp_{(L+8)}$, $freq_{-(L+12)}$, $amp_{-(L+12)}$, $freq_{(L+12)}$, $amp_{(L+12)}$,

where the subscript denotes the spin-frequency multiple, and L=LØWFS. Next, the intervals for which the spin line amplitudes exceed the noise level are listed. For each of the 8 spin lines, 20 pairs of times are given. A value of -1 means that no more intervals were found.

A spin-frequency tape is also output by the WSGSRS program. The tape, on unit 15, contains an 80-character header, followed by time/spin-frequency data pairs in the (1X,2E20.12) format. The spin-frequency data written out are median averages which are superimposed on the spin-frequency plot. A

```
**********     LEVEL(5) - DOPPLER PLOT                                     **********

WSPRCI1 - MARK RES.  14.00.06.              SEQ8847
$LEVEL5
STRTME  = -.1E+31,
ENDTME  = .28E+02,
IO3     = 13,
IO5     = 0,
TMRPLT  = F,
COHRNT  = T,
ZDSUP   = F,
DOPPLT  = .1E+01,
RATEO   = 0.0,
NFFT    = 512,
LENWDW  = 160,
LAG     = 32,
IWGHT   = 1,
HRZ1    = -.1E+31,
HRZ2    = .1E+31,
TRNC    = .2E+01,
SCLFCT  = 0.0,
PKHT    = .75E+00,
PGLEN   = .75E+01,
RDPRMS  = F,
XLEN    = .65E+01,
YLEN    = .45E+01,
NPAGES  = 0,
$END
DATA READ FROM TAPE13  HEADER -

        SITE R-395 BREAK POINT INTERVAL= .2 SEC.                  CIRPAD          11.58.03.

KEYWORDS - 1.80025194E+01   6.53152660E+04   3.20172900E+02   5.16883621E-02
PROCESSING BEGINS AT TIME =      18.002519
 HAMMING WEIGHTING USED FOR SPECTRA

NO TMR PLOT WILL BE GENERATED

R - DOT PEAKS PLOT WILL BE GENERATED WITH DATA UNWRAPPING
```

Figure 15a. Output from GSRS Analysis of Data of Figure 12

```
$TRCKER

AUTOT  = F.

LOWFS  = 20.

USELOW = T.

BINTHZ = 8E+01.

ID78   = 98.

GIDE   = 0 0.

THRESH = 1E+01.

TIME   = .182E+02. .208E+02. .23E+02. .246E+02. .2505E+02. .269E+02. -.1E+01. -.1E+01. -.1E+01. -.1E+01. -.1E+01.
         -.1E+01. -.1E+01. -.1E+01. -.1E+01. -.1E+01. -.1E+01. -.1E+01. -.1E+01. -.1E+01.

SPNFRQ = .868E+01. .739E+01. .975E+01. .985E+01. .979E+01. .914E+01. 1. 1. 1. 1. 1. 1. 1. 1. 1.
         1. 1. 1. 1. 1.

PLTLNS = F.

$END
 PLTCRX SPECTRAL TRACKER
  18.250823
  145.76     .30566   -116.83    4.5877     111.46     .39617   -111.21   3.7242   76.037    .45719
  -76.856   2.3728     41.469    .24674    -41.855    1.3737
  18.350769
  145.26     .27495   -145.93    4.5247     109.43     .30724   -110.63   4.7509   75.319    .40246
  -76.041   2.4756     41.898    .27671    -41.361     .79581
  18.450719
  143.20     .55076   -145.22    3.4857     108.25     .20562   -110.51   4.4720   74.419    .35700
  -75.270   2.9279     39.396    .25300    -37.971     .85561
  18.550661
  144.78     .80723   -144.99    2.3983     110.68     .16380   -110.06   3.5147   73.790    .61117
  -75.041   3.0624     38.771    .58624    -38.771    1.1165
  18.650607
  141.95    1.3486    -144.39    1.7517     105.68    1.8003    -108.10   3.9014   70.663   5.9310
  -74.647   2.3191     35.017    1.3055    -38.681     .76014
  18.750553
  141.33    3.1490    -144.00    1.5979     105.94    1.9579    -107.56   3.4656   70.901   7.3022
  -72.537   4.8893     35.189    1.4025    -38.771     .37060
  18.850499
  142.08    2.7330    -143.29    2.0195     106.34    2.6742    -100.81   1.0660   70.927   4.7956
  -71.289   14.233     35.019    1.5119    -36.270    1.1671
  18.950445
  142.51    2.1751    -142.74    3.0797     106.36    3.4799    -106.31    .83464  71.047   2.9529
  -71.347   14.728     35.019    2.7844    -35.019    2.6121
  19.050391
  142.31    2.6349    -142.51    4.5483     106.57    3.2796    -107.56   1.3204   71.362   3.2987
  -71.271   16.616     35.454    4.5358    -35.114    2.3246
  19.150337
  142.23    3.9462    -142.73    4.8577     106.78    1.9767    -108.18   1.4422   71.178   5.6842
  -71.076   17.778     35.605    4.8103    -34.394    1.1247
  19.250283
  142.50    4.2507    -142.53    2.7172     107.56     .63210   -107.55   2.4161   [illegible] [illegible]
  -71.171   13.207     [illegible] [illegible] [illegible] .5717[illegible]
```

Figure 15b. Output from GSRS Analysis of Data of Figure 12 (Continued)

26 045611									
129 44 -55 943 26 146557	25746 9 0173	-131 37 16 884	97881 36644	92 550 -16 884	95331 18860	-94 126	2 3739	55 030	3 [illegible]
130 07 -56 973 26 246503	10431 10 114	-132 62 18 135	1 4216 44217	93 175 -19 296	37096 77045E-01	-95 095	4 2690	55 555	2 [illegible]
132 69 -37 882 26 346449	47088 8 1711	-132 97 21 261	2 0060 63844	95 162 -19 395	1 3412 81067E-01	-95 109	5 7733	58 782	[illegible]
133 17 -59 407 26 446395	84568 6 7523	-133 02 21 518	2 0363 71226	96 309 -20 841	1 2546 93295E-01	-95 281	6 7851	57 407	8 5253
134 36 -59 669 26 546341	1 1381 7 9875	-133 64 22 785	1 7382 78453	96 895 -21 261	1 3172 11037	-96 157	5 2460	59 547	6 1984
134 58 -60 565 26 646287	1 3849 7 5165	-135 12 23 044	1 7854 86203	97 385 25 014	1 2753 51769E-01	-98 437	5 0524	60 456	6 [illegible]
135 27 -61 283 26 746233	1 2122 6 5288	-135 89 24 290	2 3475 82061	98 995 25 137	2 0045 16998	-97 [illegible]	5 8338	61 543	6 04[illegible]
136 10 -62 426 26 846179	1 0037 5 8143	-136 22 25 417	2 3077 54826	100 05 -26 890	3 5240 55151	-97 352	6 9966	62 601	6 5760
136 70 -63 465 26 946125	54054 6 1050	-136 40 26 264	1 6116 18743	100 51 -26 789	2 4774 70352	-79 752	8 1706	63 624	7 [illegible]
137 61 -64 295 27 046071	50723 6 2734	-137 40 28 904	1 2436 19006	100 72 -27 493	3 1127 08265	-100 54	8 2056	64 267	7 9678
137 66 -65 177 27 146017	1 0713 5 2794	-138 78 29 391	1 9875 27290	101 12 -28 140	3 1295 1 1259	-101 55	6 7990	64 873	7 1197
138 30 -65 925 27 245963	2 1311 5 8359	-138 62 29 187	3 6646 39079	101 84 -28 766	2 9141 39363	-102 49	4 7501	65 831	6 [illegible]
139 03 -66 355 27 345909	2 8265 6 7136	-138 38 30 555	3 8534 29606	102 76 -30 958	2 7937 24136	-102 72	4 4596	66 540	7 [illegible]
139 83 -67 370 27 445855	2 3075 5 4603	-139 85 31 267	2 5967 40526	103 18 -33 143	2 7979 11675	-103 18	4 6967	67 243	6 [illegible]
143 20 -72 539 27 545801	3 3781 4 5870	-143 20 35 019	2 8435 1 0071	108 18 -35 443	2 2426 49092	-107 77	6 4964	72 337	4 01[illegible]
143 83 -72 030 27 645747	4 2507 7 3004	-143 03 35 644	5 3532 81048	106 93 -35 644	4 0050 40299	-107 91	5 3924	72 185	3 3472
142 94 -70 663 27 745693	4 9095 16 948	-142 76 36 917	5 4541 79592	106 31 -35 019	6 8544 27377	-108 18	4 2049	70 663	8 51[illegible]
142 67 -71 208	10 397 15 151	-143 08 37 206	2 1201 2 0891	106 80 -30 146	4 8676 22084	-106 73	6 5664	70 673	17 343

MAXIMUM POWER SPECTRAL DENSITY AT ZERO-DOPPLER = 1 00670350E+02 V**2/HZ

Figure 15c. Output from GSRS Analysis of Data of Figure 12 (Continued)

THE INTERVALS FOR WHICH THE SPIN-LINE AMPLITUDES ARE SIGNIFICANT
SPIN-LINES ARE LISTED IN THE FOLLOWING ORDER -20., 20., -24., 24., -28., 28., -32., 32

18.6506067	19.3502267	19.5501207	19.5501207	19.6499387	20.1497967	20.4496347	20.6495267
20.8494187	21.1492367	21.4490947	21.4490947	22.0487707	23.0482306	23.4489146	[illegible] 9465646
26.4463946	26.7462326	27.0460706	27.7456925	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
18.2508227	19.3502287	19.6500667	19.7500127	20.7494727	20.7494727	21.3451487	21.[illegible]
21.7487327	22.3486087	22.7483526	23.0482305	23.3480666	24.8472506	25.1470966	25.9465616
26.1462566	27.7456725	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
18.6506067	19.1503367	21.0473107	21.0489787	22.2486627	24.0476906	24.2475826	25.1470965
25.3469086	25.9466646	26.2465026	27.7456925	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
18.2508227	18.8504787	19.0503907	27.7456925	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
18.6506067	19.9301207	19.7497047	20.9493647	21.1492967	27.7456925	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
18.2508227	19.4501747	19.6500667	27.7456725	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
18.6506067	19.3502787	21.2492027	21.2492027	22.2486627	22.7483726	23.1481765	23.2481276
27.4456546	27.4458545	27.7456725	27.7456725	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
18.2508227	18.2508227	18.5506607	18.5506607	18.0504907	19.1503367	27.0460706	27.0460706
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000
-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000	-1.0000000

Figure 15d. Output from GSRS Analysis of Data of Figure 12 (Continued)

value of spin frequency is written for each data time plotted. If an even number of spin-frequency values is plotted at a particular time, then the average of the interior two values is written to tape. If an odd number of spin-frequency values is plotted, then the center (median) value is written to tape.

THIS PAGE INTENTIONALLY LEFT BLANK

5. THE CONING-MOTION SOFTWARE

The TCM software makes target coning measurements via the range residual method. The range residual is the phase-derived range deviation from zero left over after the c.g. trajectory motion is subtracted from the phase-derived range data. The instantaneous range residual ΔR gives the instantaneous coning angle according to the relationship

$$\Delta R = \ell \sin\Omega_c \sin\Omega_o$$

where

ΔR = range residual,

ℓ = length from c.g. to base of missile,

Ω_o = aspect angle, and

Ω_c = the projection of the target coning angle into the plane formed by the radar line of sight and the trajectory velocity vector.

In this software the trajectory of the c.g. is determined by a polynomial fit to the square of the range. The TCM software is divided into two main programs. The first is CRSQRD, which performs the standard range-residual measurement. The second is SLR, which performs several range-squared fits in a process designed to minimize fitting error.

5.1 INPUT DATA FOR THE TCM PROGRAM

Three data files are used as input by the TCM program: (1) the WSMR site radar data tape; (2) the lowpass filtered raw amp-phase data file; and (3) the aspect-angle data file. The use of the aspect-angle file is optional when the CRSQRD program is run.

5.1.1 WSMR Site Tape

The WSMR site radar data tape is assigned to unit 1. The program uses the range data from this tape to make an initial trajectory fit.

5.1.2 LPFRAW File

The lowpass-filtered raw amp-phase (LPFRAW) file is assigned to unit IØ1 (normally unit 11). The data from this file are used to refine the trajectory fit. The fitting procedure requires amp-phase data which represent the uncorrected (raw) base return only, without interference from other scattering

centers, such as the spinning fins. The creation of this desired data file is accomplished in three steps: (1) perform the initial correction of the data using WSPRC; (2) lowpass filter the corrected data so that all but the base return is filtered out; and (3) use WSPRC to reverse the trajectory correction done in step (1) so that the data are again "raw" (i.e., so that all trajectory compensation is undone).

The first of the three steps is done exactly as previously described in Section 2.1. This step is called the initial correction. The cumulative spline breakpoints are output by WSPRC on unit 16, and must be saved for use in step (3). If two or more splines are necessary for the initial correction, they all must be saved. The initial correction is satisfactory when the central peak on the TMR plot stays between -20 and +20 Hz.

In the second step this initial-correction file is lowpass filtered by using it as input to the Acceleration, Filtering, and Decimation Program with the following parameters:

```
$PARMS
ACC=.FALSE.,
LPF=.TRUE.,
TMRPLT=.TRUE.,
NBAND=32,
IDEC=1,
NFFT=256,
LENWDW=64,
LAG=16,
HRZ1=-80.,HRZ2=80.,
$END
```

The third step is to use the output lowpass-filtered file from the second step as input to LEVEL(4) of WSPRC in order to apply the reverse of the splines saved from step (1). If two splines were used, they are assigned to units IØ4 and IØ5. If only one spline was used, it is assigned to unit IØ5, and parameter IØ4=0 is set. The input amp-phase file is assigned to unit IØ1. The following parameters would be used to reverse the correction applied by the spline on unit IØ5:

```
$PARMS
LEVEL=0,0,0,1,0,
IØ4=0,
CØEFS=0.,-1.,-1.,
$END
```

The values of CØEFS indicate that the negative of the spline is to be used. The outputted LPFRAW file is saved on IØ3. This is the file to be used as input to the TCM program.

5.1.3 Aspect-Angle Data File

The aspect-angle data file is assigned to unit IØ4 (normally unit 14). The aspect angles are used to convert the range residual into coning angle according to the relation

$$\Omega_c = \sin^{-1}[\Delta R/(\ell \sin\Omega_o)] \ .$$

The aspect-angle file consists of a 96-character header followed by time-aspect angle pairs written in the following manner:

```
      DIMENSIØN HEADER(16)
      REWIND IØ4
      WRITE(IØ4) HEADER
    1 T = new time
      A = new aspect angle
      WRITE(IØ4) T,A
      IF (more data) GØ TØ 1
      CALL ENDFYL(IØ4)
```

5.2 THE CRSQRD PROGRAM

Parameters are input to the program CRSQRD through namelist $PARMS. A header card precedes the namelist. The namelist parameters and an explanation of their use are as follows.

Name (Mode, Default)	Description
STRTME(REAL,-1.E30	The biased first time (seconds) of the time interval to be processed. Defaults to the first data time available. The time bias is obtained from the LPFRAW data described in Section 2.2.
ENDTME(REAL,1.E30)	The biased last time (seconds) of the time interval to be processed. Defaults to the last data time available.
IØ1(INT,11)	The input unit assigned to the LPFRAW data.
IØ3(INT,13)	The output unit assigned to the output corrected amp-phase data.
NAVGR(INT,40)	The number of range data points averaged into each group for the initial range-squared fit.
NAVGP(INT,0)	The number of phase data points averaged into each group for the refined range-squared fit. If not positive, defaults to NAVGR/5.
IØ4(INT,14)	The input unit assigned to the aspect-angle data. If IØ4=0, the plot of angular variation is not made.
CGL(REAL,1.5)	The length in meters from the c.g. to the base of the missile.
PLØT4(LØG,.TRUE.)	If PLØT4=.FALSE., the first three output plots will not be made.
X1(REAL,0.)	If X1≠0., the left boundary of the output plots will be X1 or the first output data time, whichever is smaller. If X1=0., the boundary is determined by the program.
X2(REAL,0.)	If X2≠0., the right boundary of the output plots will be X2 or the last output data time, whichever is greater. If X2=0., the boundary is determined by the program.

The output from CRSQRD consists of printout, four plots, and a file on unit IØ3. This output file is a scratch file containing amp-phase data corrected by the range-squared fit computed by the program.

The printout lists the parameters of the polynomials of the initial and updated range-squared fits. The input parameters and the identities of the input and output files are also listed.

Figures 16a, b, c, and d are examples of the plots which program CRSQRD produces to show the steps used in the measurement of coning motion. The first plot (Figure 16a) shows two curves representing the range residual due to the initial range-squared trajectory fit. One curve is the residual in the range data; the other is the residual in the phase data. The phase residual is the smoother curve.

The phase residual is added to the initial fit to provide refined data for another range-squared polynomial fit. The residual from this updated fit is plotted in the second plot (Figure 16b). The third plot (Figure 16c) shows the residual range variation of the base when the new fit is applied to the phase data without grouping and averaging of the data.

If aspect-angle data are available to the program (i.e., if IØ4≠0), then the range variations of the base as shown in the third plot are converted to angular motion, and are plotted in the fourth plot (Figure 16d). This plot represents the desired output from the program. The first three plots are useful primarily for ensuring that the fitting procedure was successful.

5.3 CHARACTERISTICS OF RANGE-SQUARED FITTING

In order for target coning motion to be measured, it is crucial that the c.g. trajectory be accurately determined. The generalized trajectory equation for a constant acceleration vector (e.g., for exo-atmospheric free fall over a flat earth) is

$$R = \sqrt{A + Bt + Ct^2 + Dt^3 + Et^4} \quad , \qquad (1)$$

where R is the range from a reference point (e.g., from a radar site). Within the atmosphere, however, this equation is good only as an approximation

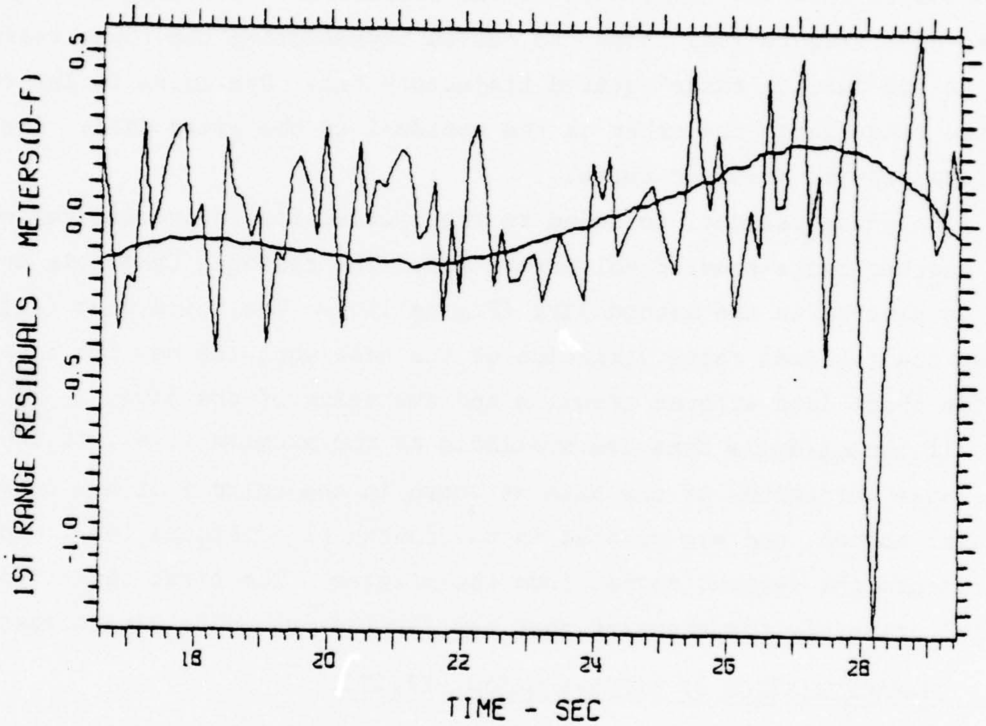


Figure 16a. Range Residual in Range and Phase Data from First Fit

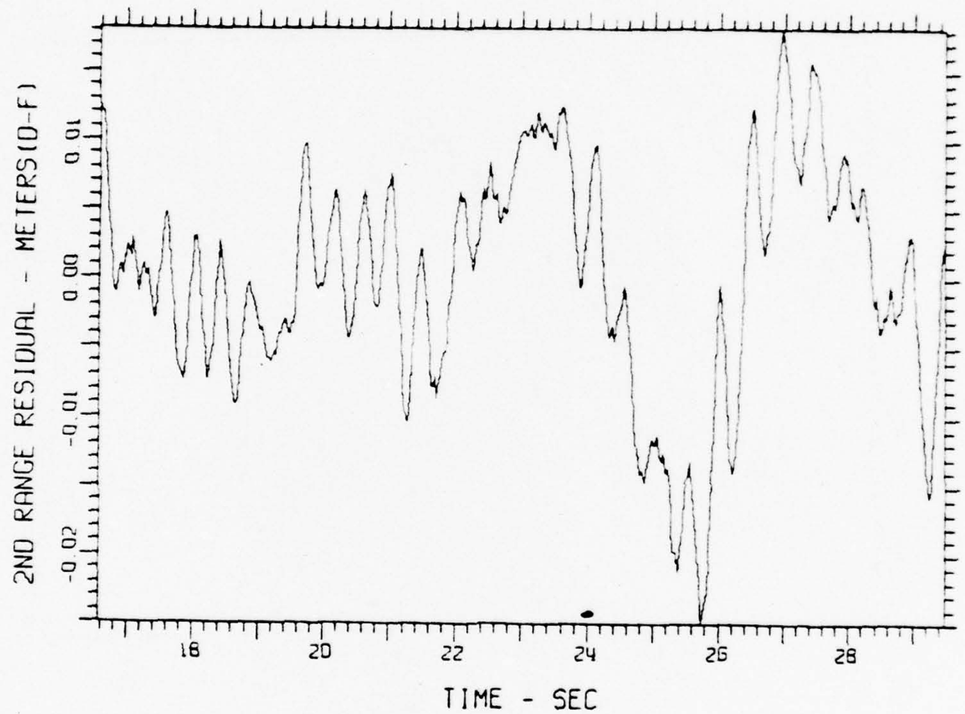


Figure 16b. Range Residual in Averaged Phase Data from Second Fit

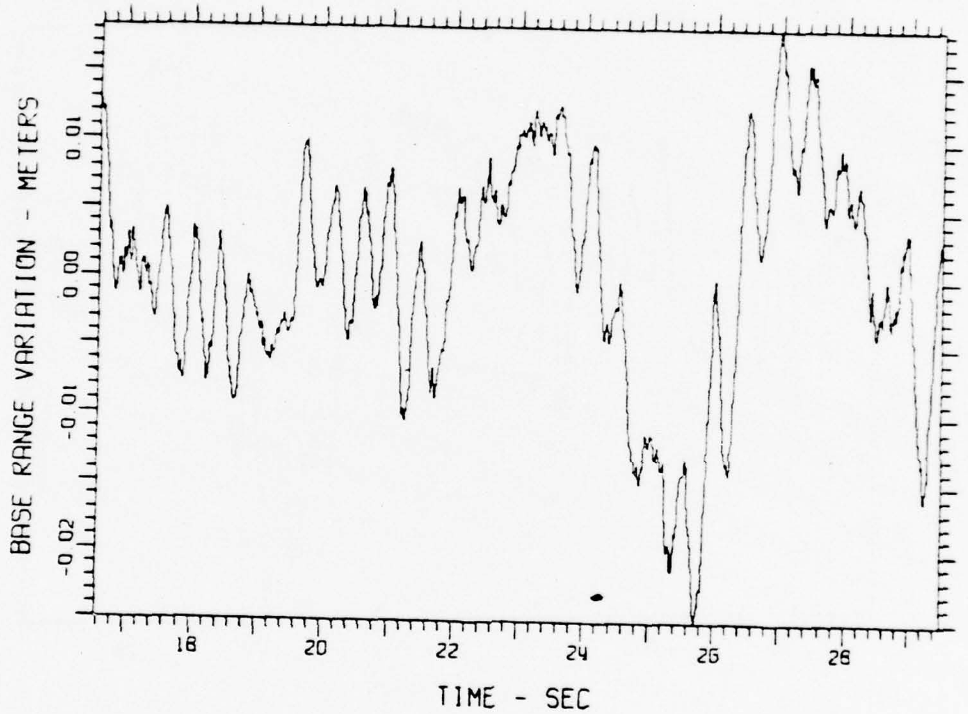


Figure 16c. Range Residual in Phase Data

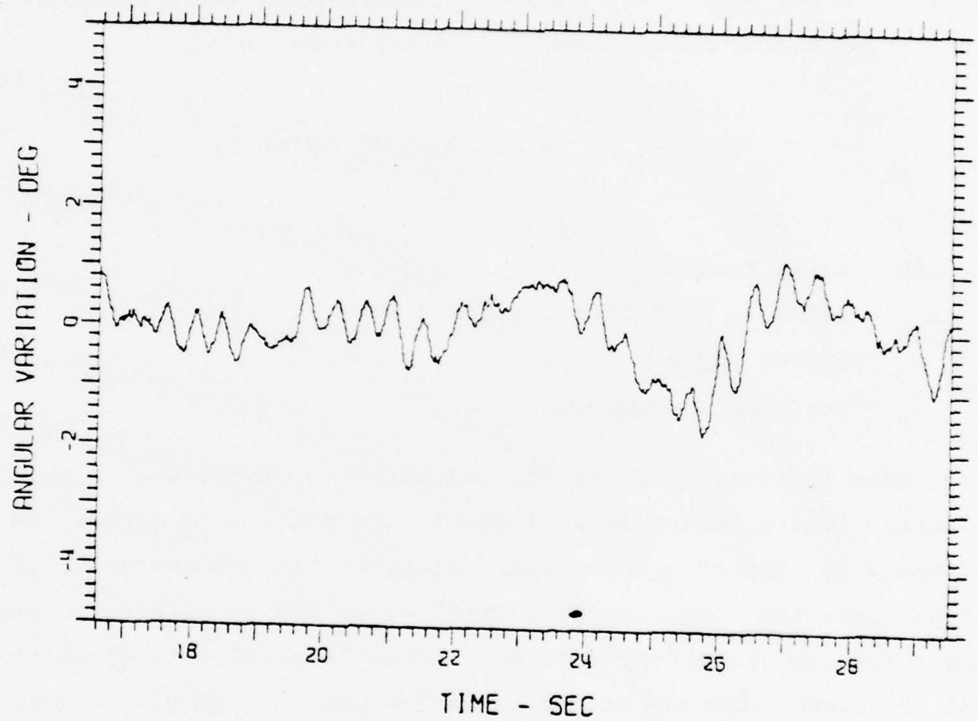


Figure 16d. Both Precession and Nutation Motions Resolved

to the trajectory over short time intervals. This is because of the non-constant acceleration due to atmospheric friction. Over a short time interval, though, one may make the assumption that the acceleration is nearly constant, and hence, the trajectory may be approximated by fitting a fourth-order polynomial to the square of the range.

When the root-polynomial fit is subtracted from the range data, the range residual remains. If the trajectory fit were perfect, *and the range measurements were to the base of the missile*, this residual would correspond exactly to the target coning motion according to the relationship

$$\Omega_c = \sin^{-1}[\Delta R/(\ell_{cg} \sin\Omega_o)] \quad ,$$

where

ΔR = range residual ,

ℓ_{cg} = distance from target c.g. to base,

Ω_o = aspect angle,

Ω_c = projected coning angle.

If the time interval used for fitting were too short, the polynomial would follow the coning motion in addition to the trajectory motion, so the residual would be less than the actual coning motion. Conversely, if the time interval were too long, the polynomial would not be able to completely compensate for the trajectory (due to a variable acceleration) so the residual would be greater than the actual coning motion. The problem, then, is to decide when the polynomial fit correctly compensates for the trajectory.

The polynomial being used for the fit is of fourth order, so it will have five extrema as illustrated in Figure 17. The polynomial can be represented by a linear combination of the zeroth through fourth-order Legendre polynomials (P_0 through P_4). The Legendre polynomials are orthogonal polynomials defined within a finite interval. After these five Legendre polynomials are removed from the trajectory, the most significant term remaining will be the fifth-order Legendre polynomial, $P_5 = 1/8\ [15x - 70x^3 + 63x^5]$, shown in Figure 18. The range residual should have this six-extrema shape when the

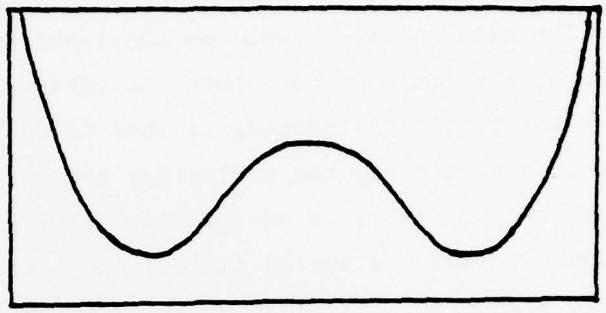


Figure 17. Fourth-order Polynomial

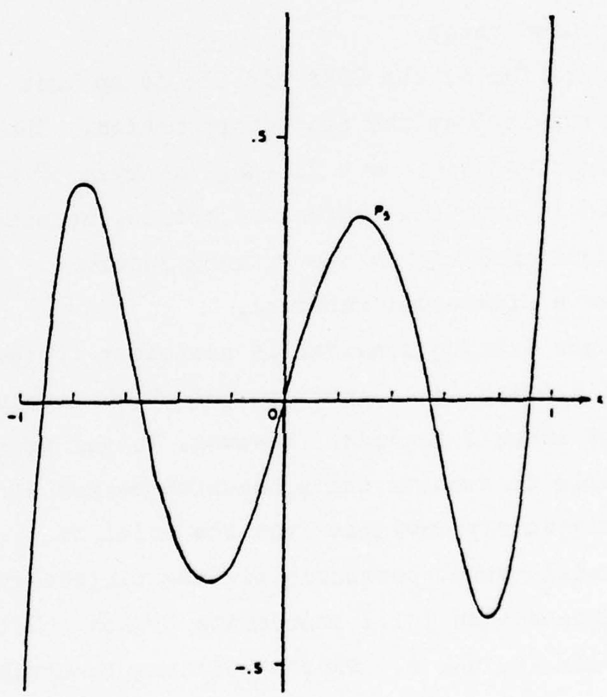


Figure 18. Fifth-Order Legendre Polynomial P_5

fitting interval is sufficiently long so that the fitting polynomial does not remove all of the trajectory motion (but when the fitting interval is sufficiently short for the P_6 term to still be negligible). Figure 19 is an example of such a residual. In that example the time interval for fitting was too long, and the residual has the characteristic shape of Figure 18. The time interval could be shortened to improve the trajectory fit, but there is a limit to how short the interval can be. This limit is reached when the fitting polynomial is able to follow the target coning motion in addition to fitting the trajectory motion. The polynomial in Figure 17 has two cycles of an oscillation. Therefore, if the time interval corresponds to two precession cycles, the precession motion will be included in the trajectory compensation and will not appear in the residual. In fact, since the fifth-order residual has two and one-half cycles, a fitting interval must be longer than two and one-half cycles of a target oscillation in order to resolve that oscillation. For example, if the precession period were 3 seconds, a fitting interval of at least 7.5 seconds would be required to separate the coning motion from the trajectory motion in the measured range.

The nutation of the GSRS missile is so fast that there is no problem in separating it from the trajectory motion. The nutation period is usually about 0.4 sec, so a fitting interval of several seconds is adequate to separate it from the trajectory motion, because then many nutation cycles are contained within one fitting interval. Figure 20 shows nutation motion over a six-second interval.

A longer fitting interval is necessary to resolve precession motion. Figure 16d shows a 13-second interval which resolves precession motion with a period of about 3 seconds. However, longer precession periods can make it impossible to resolve the precession motion so simply. This happens when the trajectory deviates from the model of Eq. (1) to the extent that the polynomial cannot correctly fit the trajectory over a time interval which is longer than 2 1/2 precession cycles. This problem is illustrated in Figures21a, b, and c. Shorter fitting intervals are used in each successive plot to remove the characteristic six-extrema residual shape. This

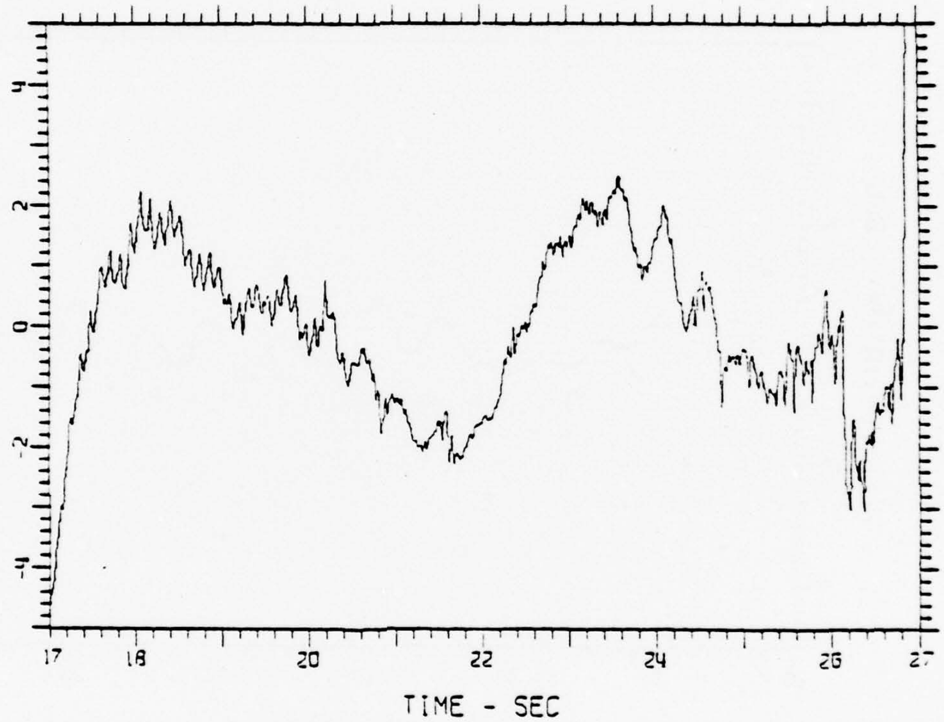


Figure 19. Residual from a 10-second Fitting Interval

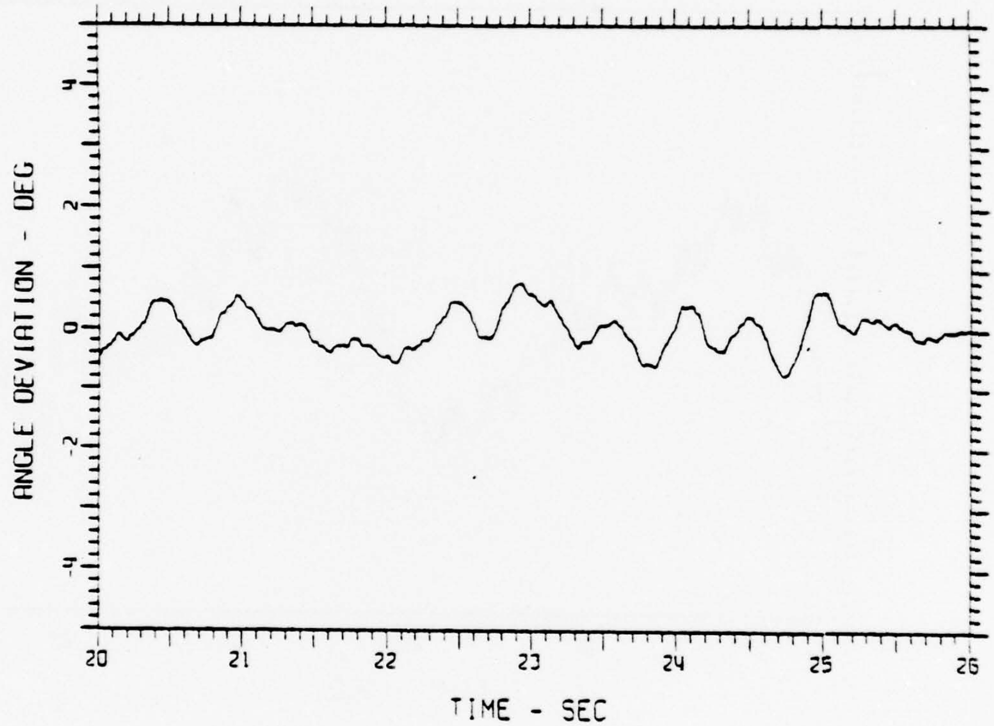


Figure 20. Nutation Motion

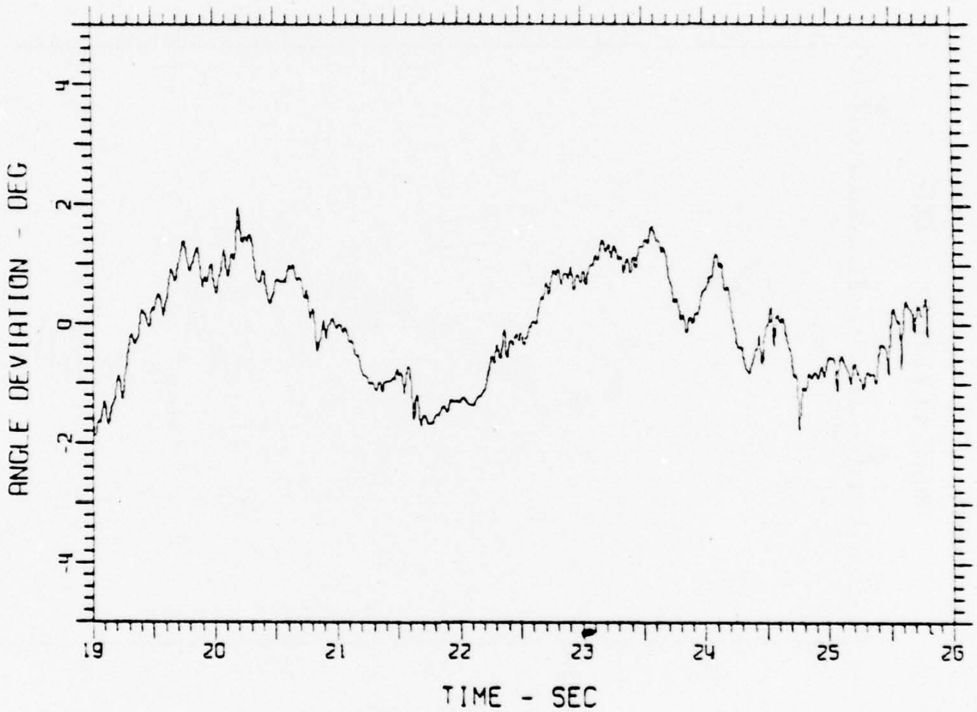


Figure 21a. Residual from a 7-second Fitting Interval

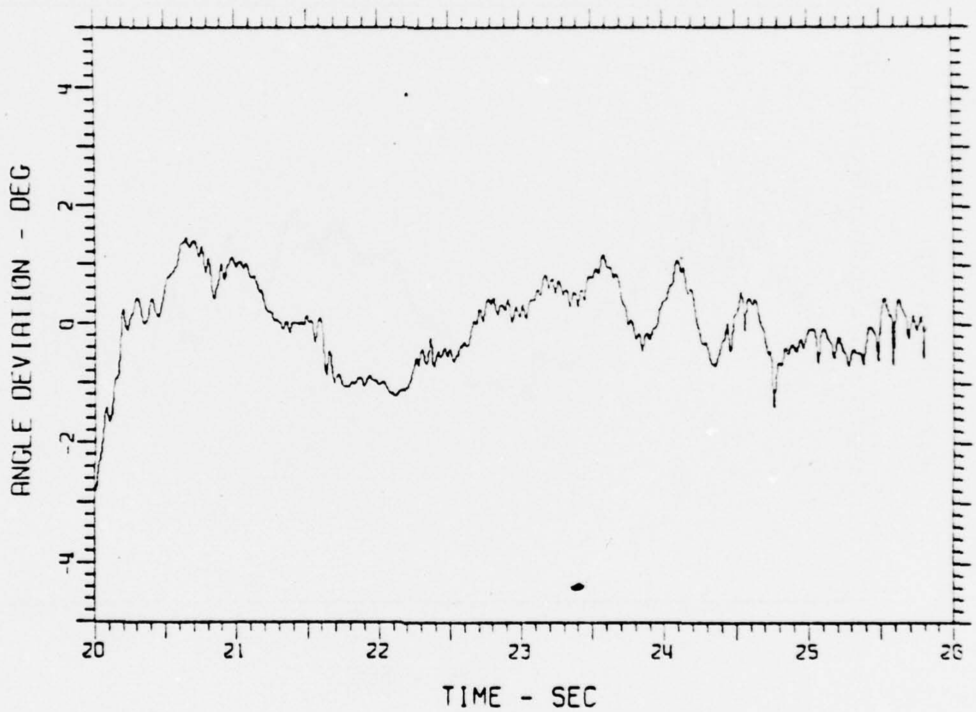


Figure 21b. Residual from a 6-second Fitting Interval

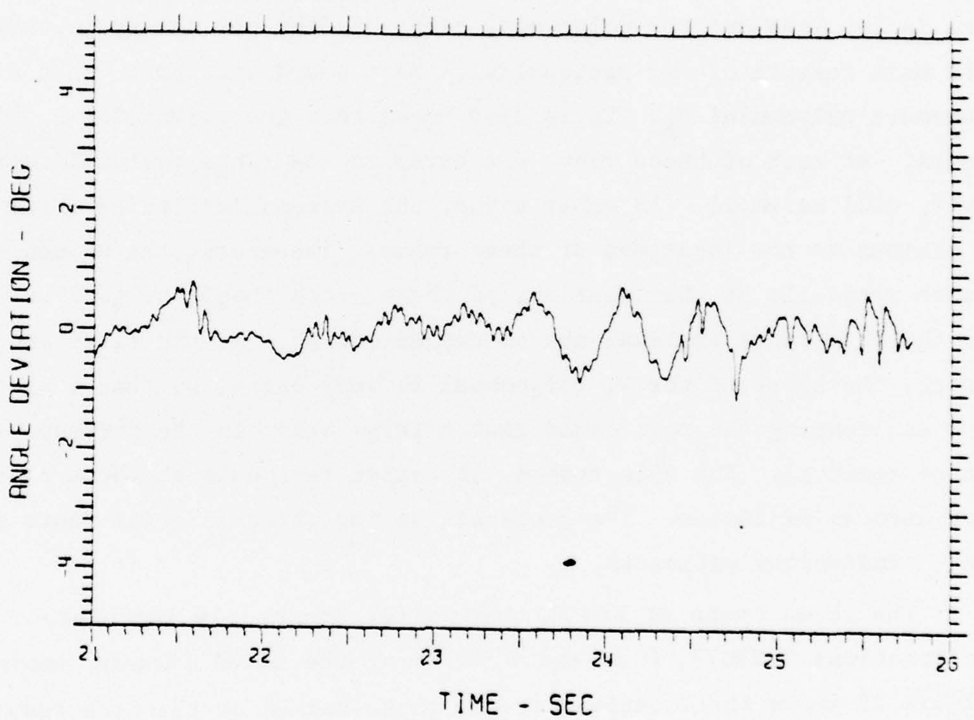


Figure 21c. Residual from a 5-second Fitting Interval

residual shape finally disappears in Figure 21c, for which the fitting interval has been reduced to 5 seconds. But in Figure 21c the precession motion is obviously removed also. In Figures 21a and 21b 2-1/2 cycles of motion are always seen, so it is impossible to determine which cycles are due to precession and which are due to trajectory residual.

5.4 THE SLR PROGRAM

There is a solution to the problem of separating trajectory and coning motion components. As explained earlier, when the fitting interval is too long and the polynomial cannot follow all the trajectory motion, the main feature of the residual will be a shape similar to that of the Legendre polynomial P_5. It is also known that the polynomial P_5 has five roots. At each of these roots the error in the range residual represented by P_5 will be small. In other words, the systematic fitting error will be a minimum at the locations of these roots. Therefore, the values of the range residuals at the locations of these roots should be good estimates of the true range residual due to target coning. At the first and last roots, the slope of the P_5 polynomial is very large, so that a slight error in locating the root could give a large error in the corresponding range residual. For this reason, the range residuals at these roots are not used as estimates. The residuals at the three interior roots give more trustworthy estimates.

The three roots of the P_5 polynomial are easily calculated. They lie at fractions 0.23077, 0.5, and 0.76924 of the total fitting interval. Figure 22 shows the locations of the roots marked on the data from Figure 19. If this fitting interval is shifted to the left or right, a new fit can be made, yielding three more range residual estimates at new times. In this manner, the entire precession motion can be constructed by sliding a fitting interval along, and plotting the three range residual estimates of each fit along the way. Figure 23 is just such a plot. Six fits were made to the data at starting-time increments of 0.42 seconds. Each fitting interval was 10 seconds in length. Three small sections of data were plotted from each fitting interval. These sections of data were centered on the Legendre roots of the various fits. A line has also been plotted which passes through the

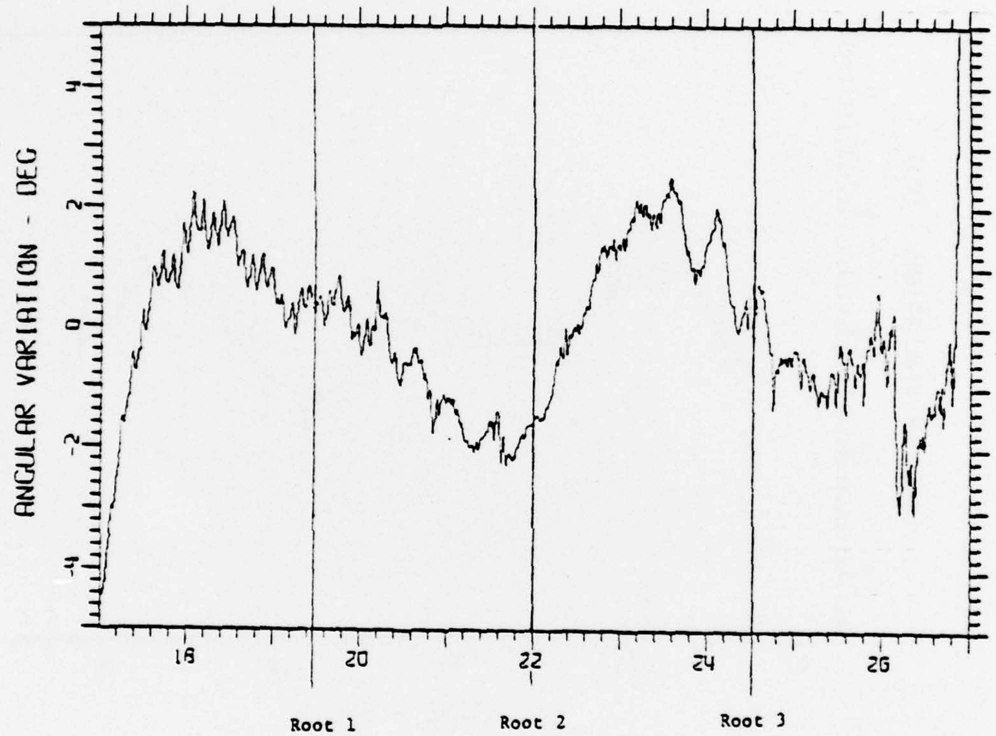


Figure 22. Roots of Legendre Polynomial P5 Marked on Residual Data

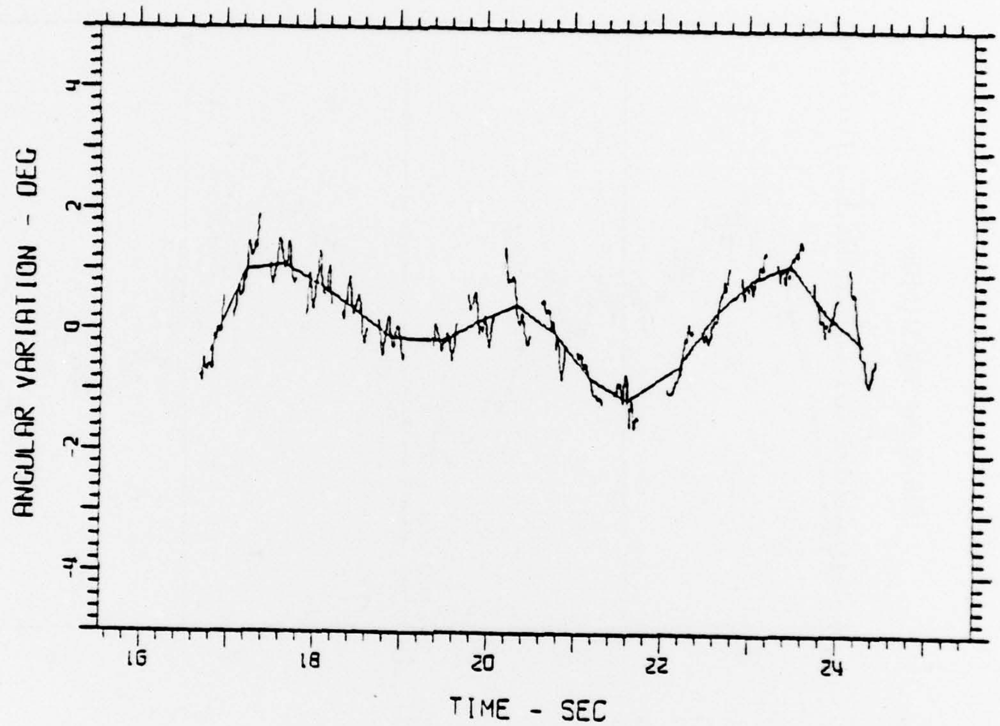


Figure 23. The Sliding Legendre Roots (SLR) Method of Target Coning-Motion Measurement

average value of each data section. This line represents the desired estimate of the precession motion. This method of target coning-motion measurement is called the Sliding Legendre Roots (SLR) method.

The plots of Figures 21 and 23 were made from the same data. Comparison of these plots illustrates the value of the SLR method in resolving precession motion.

The SLR program is executed by the TCM software when parameter SØLAR=.TRUE. is set in namelist $PARMS. Programs CRSQRD and SLR have the following parameters in common: IØ1, IØ4, NAVGR, NAVGP, CGL, X1, and X2. Program SLR does not use parameters STRTME and ENDTME. Instead, it uses several other parameters, some of which are illustrated in Figure 24. A complete list of the parameters used by program SLR follows.

Name (Mode, Default)	Description
SØLAR(LØG,.FALSE.)	If SØLAR=.TRUE., program SLR is called to perform Sliding Legendre Roots processing. If SØLAR=.FALSE., program CRSQRD is called to perform standard range-squared fit analysis.

IF SØLAR=.TRUE., the following parameters are used:

IØ1(INT,11) IØ4(INT,14) NAVGR(INT,40) NAVGP(INT,0) CGL(REAL,1.5) X1 (REAL,0.) X2 (REAL,0.)	Same as in CRSQRD (see Section 5.2)
TM1(REAL,0.)	Value of STRTME for first range-squared iteration. TM1 must be positive.
TM2(REAL,0.)	Value of STRTME for last range-squared iteration. Defaults to TM1 + .25*TMLEN*(1. - 1./ITR).
ITR(INT,6)	Number of range-squared iterations to be performed. Maximum is 20.
TMLEN(REAL,10.)	The length in seconds of each range-squared fit.

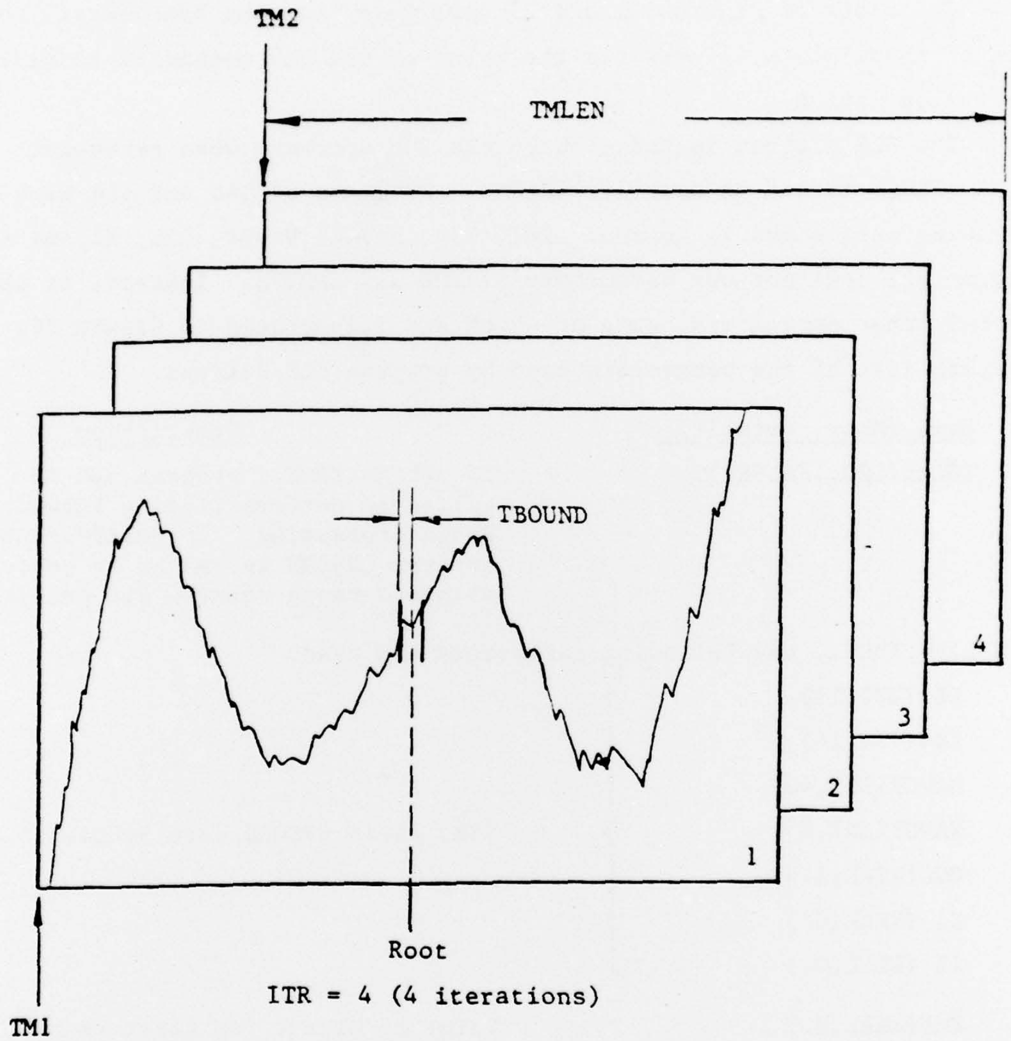


Figure 24. Parameters used by Program SLR

Name (Mode, Default)	Description
TBØUND(REAL,0.15)	Data within ± TBØUND seconds of each root is plotted. Defaults to 0.15 or (TM2-TM1)/(2.*(ITR-1)), whichever is smaller.
SPLT(LOG,.TRUE.)	If SPLT=.TRUE., the sections of data centered at the roots are plotted.
LPLT(LOG.,TRUE.)	If LPLT=.TRUE., line segments are plotted joining the averaged centers of the sections of data.

A desired SLR plot, like the one in Figure 23, can usually be made by setting SØLAR=.TRUE., defining TM1, and letting all the other parameters default. If data are not available up to TM2 + TMLEN seconds, processing will stop short of completion. It is important that a suitable length of time be chosen for the fitting interval TMLEN. In Figure 23 the default value of 10 seconds was used. Due to considerations previously discussed, TMLEN should be long enough so that the P_5 polynomial is the dominant shape in the residual. Usually for the GSRS, 10 seconds or longer will be suitable, and the fitting interval will contain approximately 4 or more precession periods.

5.5 EFFECTIVE USE OF THE CONING-MOTION SOFTWARE

The CRSQRD and SLR programs are an effective combination for measuring target coning motion. Program CRSQRD should be used whenever possible to accurately measure coning motion. The fitting interval used should be the longest interval possible which does not introduce a systematic error into the trajectory compensation. The nutation of the GSRS missile is invariably rapid enough to be easily resolved by the CRSQRD method. In some cases, however, it will be impossible for the CRSQRD program to resolve the slower precession motion. In these cases, program SLR should be used to resolve the slower motion.

Whenever possible, concurrent data from several radars should be analyzed and compared to confirm observations and to improve accuracy. It should be remembered that each radar sees the projection of the coning motion into a different plane, so the results will not correspond identically. The

general pattern of the coning motion, however, should be the same in the analysis of each radar's data.

6. SOFTWARE ON THE RADAR GRAPHICS LABORATORY

Programs WSGSRS and TCM have been implemented as tasks on the PDP-11/55 Radar Graphics Laboratory (RGL). The usage of these tasks on the RGL and on the Univac 1108 is identical except for a few features which will now be described.

The tasks should be run from the graphics terminal (as opposed to the printer terminal). The software accepts the input parameters from the terminal by displaying the parameter name followed by its present value. A carriage return on the keyboard leaves the parameter unchanged. To explicitly set the parameter, type the desired value followed by a carriage return. After all parameters in the namelist have been entered in this manner, the procedure may be repeated to correct any mistakes which may have been made in typing in the values. Headers and filenames are also entered in this manner. On the RGL files are specified by file names during execution of the software, rather than by logical unit assignments specified in control cards.

The parameters PAUSE and HRDCPY have been added to the namelists of these tasks on the RGL. The logical variable PAUSE determines whether or not the software will pause at the end of each plot. If PAUSE equals .TRUE., execution of the task will pause at the completion of each plot page, pending the receipt of any keystroke from the terminal, upon which execution resumes. Logical variable HRDCPY determines whether or not *automatic* hard copying of plots is invoked. The default values are PAUSE=.FALSE. and HRDCPY=.TRUE., so that in the default case plot pages are automatically copied and no action is required of the operator.

6.1 THE SPIN-FREQUENCY TASK

The spin-frequency task WSGSRS is executed on the RGL by the following command:

```
@RG:[100,100]RUN SPIN
```

This software uses the following input parameters which are not implemented in the Univac version.

Name (Mode, Default)	Description
YMIN(REAL,6.)	The lower limit (in Hz) of the spin-frequency plot.
YMAX(REAL,12.)	The upper limit (in Hz) of the spin-frequency plot.
PRNTSP(LØG.,.FALSE.)	Spin-frequency data from the scratch file are not printed unless PRNTSP equals .TRUE.

The LEVEL(5) namelist $PARMS on the RGL contains only parameters relevant to spin-frequency processing. These are STRTME, ENDTME, NFFT, LENWDW, LAG, CØHRNT, ZDSUP, IWGHT, HRZ1, HRZ2, XLEN, YLEN, PAUSE, and HRDCPY.

The spin-frequency software asks whether or not the averaged-spin file is to be created. If the answer is yes, the output file is created with a name given by the operator.

6.2 THE CONING-MOTION TASK

The coning-motion task TCM is executed on the RGL by the following command:

```
@RG:[100,100]RUN TCM
```

One additional input parameter is used in this version of program TCM. The logical parameter CTAPE allows for the creation of an unformatted data file consisting of a 100-character header followed by time/coning angle data pairs. The data are the points which are plotted in the angular variation plot. If CTAPE equals .TRUE., the data file is created on the system disk with the name FØR010.DAT.

6.3 THE SPLINE FILE TASK

Task SPFILE has been implemented on the RGL to perform the creation and editing of spline files by hand. This task is executed by the following command:

```
@RG:[100,100]RUN SPLN
```

The task asks for spline data which it writes to a spline file in the WSPRC format. The default data values presented by the program come from an

existing spline file (in the case of file editing), or from calculations (in the case of file creation). When editing a spline file, breakpoints may be inserted, deleted, and altered. The program asks for the breakpoint time, and then for the $\dot{R}$ value. If a new file is being created, the program displays the current default range value R_R calculated according to the relation

$$R_R = R_L + \frac{1}{2} (\dot{R}_L + \dot{R}_R)(T_R - T_L) \quad ,$$

where the subscript R denotes the new breakpoint, and the subscript L denotes the last breakpoint. This feature simplifies the creation of hand splines because all that is required is to read time and $\dot{R}$ from the Doppler peaks plot, to enter these values, and to use the default values for range.

THIS PAGE INTENTIONALLY LEFT BLANK

7. MEASUREMENT ACCURACIES

Spin-frequency and coning-motion measurements of GSRS motion have not been made during the boost phase of the missile's flight. This is because during the boost phase the radar skin return is obscured by the exhaust gases. Accurate measurements can be made, however, after the boost phase.

7.1 SPIN FREQUENCY

Figure 13 shows the spin frequency measurement of a GSRS flight. The accuracy obtainable is on the order of $\pm$ 0.03 Hz, which is the average width of the composite line formed by superimposing the several individual spin-frequency measurements made by the WSGSRS program.

7.2 CONING MOTION

Figures 16d and 20 show good measurements of nutation motion. Some modulation will be seen in the amplitude of this motion since the angle measured is the projection of the coning angle into the plane formed by the radar line of sight and the GSRS trajectory vector. The accuracy of the measurement of this projected angle is on the order of $\pm$ 0.3° (~ 5 mil) which is the approximate amplitude of the noise seen in the two plots. The measurement of the slower precession motion is less accurate. The estimated accuracy of precession measurement in Figure 23 is $\pm$ 0.5°.

THIS PAGE INTENTIONALLY LEFT BLANK

DISTRIBUTION LIST

Organization	Number of Copies
STEWS-NR-A	1
CCNC-TWS	2
STEWS-NR-D	4
STEWS-NR-P	2
STEWS-PL	1
STEWS-PT-AL	3
STEWS-PT-AM	1
STEWS-QA	1
STEWS-ID	2
STEWS-TE-LD	3
Commander US Army Test and Evaluation Command ATTN: DRSTE-AD-I Aberdeen Proving Ground, Maryland 21005	2
Director of Research and Development Headquarters, US Air Force Washington, DC 20315	1
Director US Naval Research and Development Department of the Navy ATTN: Code 463 Washington, DC 20390	1
Commander Air Force Cambridge Research Center L. G. Hanscom Field ATTN: AFCS Bedford, Massachusetts 01731	1

Commander
US Naval Ordnance Test Station
ATTN: Technical Library
China Lake, California 93555 2

Director
National Aeronautics and Space Administration
ATTN: Technical Library
Goddard Space Flight Center
Greenbelt, Maryland 20771 2

Commander
Pacific Missile Range
Point Mugu, California 93041 1

Director
OSD-OUSD-RE-DDDTE (Mr. Don Greenlee)
Room 3D1043, Pentagon
Washington, DC 20301 1

Commanding Officer
Naval Air Missile Test Center
Point Mugu, California 93041 2

Office of the Chief
Research and Development
Department of the Army
Washington, DC 20310 3

Commanding Officer
US Army Electronics Command
Meteorological Support Activity
ATTN: Technical Library
Fort Huachuca, Arizona 85613 2

Commanding Officer
US Army Ballistics Research Laboratories
Aberdeen Proving Ground, Maryland 21005 1

Commanding Officer
US Army Research Office
P. O. Box 12211
Research Triangle Park, North Carolina 27709 1

Commander
Atlantic Missile Range
Patrick Air Force Base, Florida 32925 1

Commanding Officer
US Army Aviation Test Activity
Edwards Air Force Base, California 93523 1

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22314 2

Department of Army
Office of Deputy Chief of Staff for
Research, Development and Acquisition
ATTN: DAMA-AE-E
Washington, DC 20310 1

Commander
HQ, 14th Aerospace Force
Ent AFB, CO 80912 1

Headquarters
P. O. Box 92960
Worldway Postal Center
ATTN: CPT Ken Murphy, RSP
Los Angeles, CA 90009 1

Commander
Vandenberg Air Force Base
ATTN: SAMTEC (XRE) (Mr. Kingston George)
Vandenberg AFB, CA 93437 1

Commander
DMBSCOM-RD
ATTN: Mr. Tom Keeney
P. O. Box 1500
Huntsville, AL 35807 1

US Army Materiel Systems Analysis Agency
ATTN: DRXSY-MP
Aberdeen Proving Ground, MD 21005 1

Commander
Army Materiel Development and Readiness Command
ATTN: DRCAD-P
5001 Eisenhower Avenue
Alexandria, Virginia 22333 1